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RONALDS AND RICHARDSON'S

CHEMICAL TECHNOLOGY;

OR,

CHEMISTRY IN ITS APPLICATIONS

TO THE

Arts and Manufactures.

NEW EDITION.

VOL. I.—PART II.

ERRATA.

Page 570, line 20.—*After* "Arley" *insert* "Main."

" " " 2 from bottom.—*For* "Sydney" *read* "Lydney."

" 574 " 21.—*For* "carburetted hydrogen" *read* "carbonic oxide."

" 575 " 1.—*For* "English caking" *read* "small;" and in lines 3, 4, 8, & 11, *after* the words "Pelaw" and "Pelton" *insert* "Main."

" 576 " 8-19.—*For* "Mr. J. Evans" *read* "Mr. F. J. Evans."

" " " 1, 20-2, 31-2.—*For* "Mr. Joseph Hedley" *read* "Author of Chemistry of Gas-lighting."

" 587 " 4.—*For* "Pancras" *read* "Fulham."

" 590 " 5.—*For* "clay" *read* "fire-bricks;" and, as a further description of Scotch cannel coals, *add* "containing 50 to 60 per cent of volatile matter."

" 596 " 4 from bottom.—*For* "Croll" *read* "Lowe."

" 601 " 29.—*For* "a saving of 10 per cent" *read* "a tenth of the fuel."

" 604 " 13.—*For* "luminous" *read* "luminiferous."

" 619 " 4 from bottom.—*After* "Hull" *insert* "Taunton."

" 630 " 13.—*After* "olefiant gas" *insert* "and hydrocarbon vapours."

" 632 " 23.—Make the same addition.

" 642 " 21.—*Omit* "and purify;" and *before* "coal" *insert* "cannel." Conclude the paragraph with, "and the quality of the gas required to be produced."

" 643 " 4.—*For* "900" *read* "9000."

" 644 " 8.—*For* "equal to" *read* "not exceeding."

" 651 " 15.—*After* "surround them" *insert* "Pauwels and Dubochet's patent has been successfully adopted at the London Gas Works, Vauxhall."

" 671 " 10.—*For* "fish- or swallow-tail" *read* "union-jet or fish-tail."

CHEMICAL TECHNOLOGY;

OR,

CHEMISTRY APPLIED TO THE ARTS

AND

MANUFACTURES.

THE APPLICATION OF FUEL TO THE PRODUCTION OF LIGHT.

General principles.—The production of artificial light depends upon the well-known and easily-observed fact, that the action of high degrees of heat upon bodies which are not volatile, always renders them luminous, the requisite heat being produced either by the chemical process of combustion, or more rarely by the passage of the electric current.

Bodies of different chemical and physical constitution, however, exhibit this property in very different degrees, so that a temperature which only produces visible incandescence in gases, causes solid bodies, such as iron, to emit a vivid white light. Temperature is consequently not the sole cause of luminosity, but other properties, and more particularly the density of the heated bodies, play an important part. For this reason little is to be expected from purely gaseous matter as a source of light, while solid particles of some kind are brought to [illegible] incandescence by the heat evolved during [illegible] combustion. The conditions which are essential to the production of light combine. Therefore, a substance or substance [illegible] electrical change which generates [illegible] and to some solid body renders [illegible] ing *light*.

For [illegible] mination of micro copic

objects under a high magnifying power, a very intense light is required,—superior even to that of the sun. Here, expense being a secondary consideration, the oxyhydrogen or blow-pipe flame is so applied as to render a piece of lime incandescent; the conditions are thus rigidly followed, the most refractory or fire-proof substance is heated by the most intense flame. In this instance the incandescence is produced in a substance altogether foreign to the heating material, and which takes no part whatever in the process of combustion; and the same principle has been recently applied to increase the luminosity of the ordinary gas-flame, by means of platinum. All the different plans of obtaining artificial light in common use, involve the employment of some substance which during the process of combustion evolves a solid body, carbon, which is heated to incandescence before being consumed.* The solid carbon evolved at one period of the process, therefore, takes the place of the lime in the previous case, and is rendered luminous in proportion to the heat generated.

Chemistry has made us acquainted with numerous bodies which during combustion become luminous, with the evolution or formation of solid compounds, but very few are adapted to the purposes of general illumination. Phosphorus and zinc, for instance, burn with a brilliant light; the phosphoric acid formed in the one case, and the oxide of zinc in the other, remaining for a few moments within the sphere of combustion, and becoming incandescent; but neither of these substances could be employed for illumination under ordinary circumstances, because the products of combustion, oxide of zinc and phosphoric acid, are not volatile, and, being deposited in the immediate vicinity of the flame, are injurious and troublesome. It is, therefore, absolutely necessary that the products of the combustion of the illuminating materials should be volatile, so as not to interfere with the course of the process. The incandescence of the carbon, which is ultimately consumed, and passes off in the form of gas (carbonic oxide or carbonic acid), is the source of light in the flames of coal-gas, candles, and lamps; and the combustion of the carburetted hydrogens derived from these sources is peculiarly adapted to illustrate this subject.

If carburetted hydrogen is ignited in contact with air, both its elementary constituents enter into combination with oxygen, but not at the same moment of time, the hydrogen being the more

* A little instrument, invented by Mr. Goddard, of Ipswich, is admirably adapted to demonstrate this fact.

combustible. The phenomena, therefore, succeed each other in such a manner, that the hydrogen is first consumed as a gas, evolving an almost imperceptible light, but a very intense heat, which causes the nascent carbon to become incandescent, and consequently luminous. In the next moment, however, the incandescent floating carbon is brought to the edge of the flame, where there is abundance of air to consume it, carbonic acid is produced, and its place is immediately occupied by another portion of solid carbon. If carburetted hydrogen is mixed with chlorine, the same order of combination is observed, but the first act ends the process; on ignition, the hydrogen burns to form hydrochloric acid, and the carbon is deposited in the form of powder or soot. In the air, the soot is burnt a few seconds after its production, which is not the case in chlorine gas. The variable illuminating power of different carburetted hydrogens is thus explained. Fire-damp contains 1 part by weight of hydrogen to 3 of carbon; 1 part of hydrogen requires 8, 1 part of carbon 2.666 parts of oxygen for combustion. Supposing the oxygen of the air, which takes an active part in combustion, to combine with both simultaneously, then 8 parts of oxygen would combine with 1 part of hydrogen, and the same quantities would be required to consume the 3 parts of carbon. In olefiant gas, 1 part of hydrogen is combined with 6 parts of carbon: on the same supposition that one of hydrogen and three of carbon are simultaneously consumed, there will remain an equal amount of carbon unburnt, which is consequently liberated and rendered incandescent. Although the hydrogen is in reality always consumed first, yet it is obvious that olefiant gas is capable, under similar circumstances, of supplying more carbon to the flame, and consequently of producing more light. Oil of turpentine contains 8, coal-tar naphtha nearly 10 parts of carbon to 1 of hydrogen. Most bodies of organic origin that are decomposed by heat, give rise, amongst other products, to gases and vapours which are indebted to the presence of one or other of the hydrocarbons for their property of burning with a luminous flame. If these consist of olefiant gas, or of hydrocarbons still richer in carbon, the flame is more luminous than if fire-damp or similar compounds compose their chief bulk. The former are generally the product of [illegible] in carbon. It has already been shown that wood, co[illegible] hydrogen, and 43.8 oxygen, su[illegible]ut 25 per cent of carbon, and th[illegible] the other elements in the

products of distillation; but 6.2 per cent of hydrogen requires 37 parts of carbon to form olefiant gas; there is consequently an insufficient quantity of carbon in the products of the distillation to produce that gas, while there is at the same time a quantity of oxygen. Wood is on this account not adapted for illuminating purposes; but it is very different with the fats. In olive oil, for instance, nearly the whole of the 77 per cent of carbon which it contains passes over with the volatile products, when it is decomposed by heat, and this more than suffices to form oil-gas with the 12 per cent of hydrogen which remains after the whole of the oxygen has taken up as much as is required to form water. Good coal containing from 80 to 85 per cent of carbon, only produces from 50 to 60 per cent of coke, and, although better than wood, is therefore inferior to oil as a source of light. The value of any material as a source of light thus depends not alone upon the quantity of carbon it contains, but also upon its chemical and physical constitution. Besides the selection of proper material for evolving highly carbonaceous gases on the application of heat, it is equally important to attend to the mode of combustion, and to the order in which the different ingredients are consumed, which must be so regulated as to afford the largest amount of light. When the fats, and similar substances, which leave no residue on carbonization, are employed, the illuminating gases may be burned as they are evolved from the material which supplies them, as in the case of candles and lamps. With coal and resin, on the contrary, and all similar substances which leave carbon and other matters as a residue on distillation, the production of the illuminating gases forms a distinct process from their subsequent combustion in producing light. The study of these processes must, from the nature of the subject, be preceded by a review of the materials most generally employed.

The material for producing light.—Among natural and artificial products, there are many which are chemically adapted for the production of light, but only a few can be obtained in sufficient quantity and at a price to render them available for so general and extensive an application: these are coal, resin, tallow (stearine, stearic acid), spermaceti, wax, and some of the fat and volatile oils, both of vegetable and animal origin.

The Fats. Composition.—These products of organic life are found very generally diffused in nature, and play a very important part in domestic economy, being largely consumed as food, indispensable to the production of soap, and admirably adapted to the production

of light. Although solely derived at present from the organized structures of plants and animals, it may, perhaps, be reserved for chemistry, in its rapid progress, to point out a cheap mode of producing the fats artificially; at least, the recent discovery of Pelouze, who has succeeded in producing *butyric acid* by subjecting *sugar* to a fermentative process with the aid of cheese, appears to have opened the way in that direction. The fats will always command their highest value when they can be employed as food, and it is only when they are obtained in superabundance, or in a form which renders them unpalatable, that they are used as sources of light and for the production of soap. Their suitableness as food, and as sources of light, is chiefly due to the large quantities of carbon (70—80 per cent) which they contain as compared with that of the other two constituents, hydrogen and oxygen,—a preponderance which also distinguishes them from most other bodies of organic origin. In the state in which the fats are taken from animal and vegetable bodies, they are not homogeneous chemical combinations, but mixtures of several different compounds, each of which exhibits the general properties of the whole class. Some of these fatty compounds or proximate constituents are solid at common temperatures, as *stearine* (from στεαρ, tallow); others are fluid even at 0° C. (32° F.), as *oleine* (from ἔλαιον, oleum, oil). In mutton tallow, the solid fatty ingredient was long regarded as a distinct fat, and on account of its mother-of-pearl lustre it was called *margarine*. It has since been shown by Heintz, that margarine is a mixture of stearine with *palmitine*, which latter substance forms one of the principal ingredients in most of the animal fats, and, as its name indicates, is largely contained in palm oil.

Thus the natural fats are mixtures, in variable proportions, of several distinct fatty compounds, some of which are solid, and others liquid at ordinary temperatures. The larger the amount of solid ingredients, the higher is the melting point of the compound fat. The different varieties of tallow are solid, the oils liquid; while, intermediate between the two, range the various kinds of grease which possess a salve-like consistence. No mode of burning the latter for lighting purposes has hitherto been invented, and they are generally too costly for being converted into gas; the liquid oily portions are, however, often expressed, when the solid is applicable to the manufacture of candles.

The following table shows the composition of some of the oils and fats employed for giving light in the crude state:—

Name of Oil.	Carbon.	Hydrogen.	Oxygen.	Analyst.
Olive oil	77.21	13.36	9.43	Gay-Lussac and Thénard.
Train oil	76.13	12.40	11.50	
Oil of Squalus maximus	82.77	12.96	4.27	Ronalds.
Sperm oil	78.9	10.97	10.13	Ure.
Spermaceti	81.60	12.80	5.60	Chevreul.
Wax, bees-	81.80	12.67	5·54	Gay-Lussac and Thénard.
„ Brazilian	74.11	11.77	14·12	Oppermann.
„ East Indian	70.97	12.07	16·97	
Tallow, animal	78.10	11.70	9·30	Chevreul.
Resin	79.27	10.15	10·58	Sell and Blanchet.
Oil of turpentine	84.60	11.73	3.67	Oppermann.
Paraffine	85.22	14.78		Reichenbach.

The other vegetable and animal oils and fats employed for illumination have not been analysed in the crude state: they are mixtures principally of stearine, palmitine, and oleine, while some contain peculiar fatty substances, the composition of which will be noticed with the special description of each.

The specific gravity at 15° C. (59° F.) of most of the fats is less than that of water: thus—

	Sp. gr.		Sp. gr.
Oil of Brassica campestris	0.9136	Beeswax	0.9660
„ „ napus	0.9128	Brazilian wax	1.0100
Olive oil	0.9176	East Indian wax	1.0100
Palm oil	0.968	Spermaceti	0.9430
Madia oil	0.9170	Train oil	0.9270

The temperatures at which these fats pass from the fluid to the solid state, and *vice-versâ*, are very variable, and were found as follows for—

Oil of B. napus	−6° C. (21° F.)	Brazilian wax	+97° C. (207° F.)
„ „ campestris	−4° „ (25° „)	East Indian wax	+49° „ (121° „)
Olive oil	+2°.5 „ (36°.5 „)	Train oil	0° C. (32° F.) impf.
Madia oil not even at	25° „ (77° „)	Spermaceti	44°.7 C. (112° F.)
Palm oil	29° „	Tallow	37° to 40° C. (99°–104° F.)
Beeswax	+63° „ (145° „)		

According to Duffy, the solid fats often exist in allotropic conditions, when they exhibit very different melting points; so that the melting point can only be taken as an index of the purity of a fat under the same physical conditions.

With the exception of some few, the fatty bodies employed for illuminating purposes are fixed, or do not evaporate on exposure, like the volatile oils, nor can they be heated strongly without decomposition. It is, consequently, impossible to ascertain their boiling points; and this property also distinguishes them from the volatile oils, to which oil of turpentine, naphtha, and

paraffine belong. When raised to a high temperature they assume the appearance of ebullition, evolving very pungent vapours, and are resolved into a great number of new products. Their basic ingredient, glycerine, is converted by heat into acroleine, which gives the irritating property to the vapours of boiling oil; their oleic acid is partly converted into sebacic acid, while the stearic and other fatty acids are in part volatilized, and partly undergo conversion into carburetted hydrogen, carbonic acid, and other products, leaving carbon as a residue. The fixed oils are, in consequence of this partial conversion into gaseous hydrocarbons, employed in some countries as sources of illuminating gas.

Most of the fat oils become rancid by exposure to the air, which is due to the action of atmospheric oxygen, and distinguishes them as a class from the drying oils, such as linseed, nut, and poppy-seed, which are converted by the same agency into resins. Great heat accompanies this union of oxygen with the elements of the oil, so that spontaneous combustion has often resulted from the exposure of an extensive surface of oil in tow or other porous waste employed by engineers in cleaning machinery.

Dr. Griseler has made the observation that a few drops of nitric ether entirely prevent rancidity in fats, and even destroy the disagreeable smell of oil that has become rancid.

The fat oils are decomposed by chlorine, which combines with their hydrogen, and can consequently only be used in particular cases for bleaching them. Nitric acid and sulphurous acid convert many of them into a solid substance called *elaidine*. Strong sulphuric acid combines with the fatty acids, and also with the glycerine of the oils, forming with both ingredients compound acids,—*sulphostearic, sulphopalmitic,* and *sulphoglyceric acids*. These compound fatty acids are decomposed by water into sulphuric acid, which dissolves, and slightly modified fatty acids, which float on the surface of water; and this reaction is now carried out on a most extensive scale in the manufacture of stearic acid candles.

Strong alkalies and lime likewise decompose the fats, combining with the fatty acids and liberating glycerine. This reaction, which forms the basis of operations in the manufacture of soap, is also very extensively employed as a means of separating the fatty acids for the manufacture of candles.

Of all fluids, the oils expand the most by heat, and, indeed, to such a degree, that it becomes necessary for commercial purposes to know the extent of this expansion. For every degree of the centigrade thermometer the volume of olive oil increases, according

to Preisser, $\frac{1}{1400}$; of rape oil $\frac{1}{1120}$; and of train oil $\frac{1}{1000}$; so that 100 measures of train oil at 0° C. will become 102 measures in summer at 20° C. Another property in which the different fluid oils vary considerably, and which has considerable influence upon their value as combustibles, is their degree of fluidity, which is estimated by the time required for a given quantity of oil to flow through a funnel of known dimensions. Schübler and Ure obtained the following results upon this point:—

Fluids.	Time required to flow through a given aperture.	Fluidity. Water=100.
Water	90 seconds.	100
Oil of Brassica campestris	162 „	55.5
„ „ napus	159 „	56.6
„ „ præcox	148 „	60.8
„ „ napo-brassica	142 „	63.3
„ „ rapa	136 „	66.1
Olive oil	195 „	46.1
Train oil, according to Ure	450 „	20.0

Adulteration of Oils.—The more expensive fat oils of commerce are often adulterated with cheaper oils, and the detection of these fraudulent admixtures is attended with much difficulty. This is less the case with such as are employed for lighting, than with those which are used as food. Olive, sperm, and some others, are, however, often adulterated with inferior drying or fish oils.

The source whence an oil has been derived may in many instances be ascertained by the smell which it evolves when gently warmed over a lamp. In this manner linseed, whale or train, and rape oil, discover their presence when used to adulterate the more expensive oils; but the test is not altogether trustworthy, as oil extracted in the cold evolves a different odour to the same kind of oil expressed with heat, and the place of growth is said to affect the smell of olive oil.

The specific gravity is sometimes made a test of the purity of oils. For this purpose the specific-gravity bottle may be employed, Gay-Lussac's alcoholmeter, or an oleometer; which latter is used in Saxony, constructed in such a manner that pure rape-seed oil is indicated by 37° to 38°, hemp oil by 30° to 31°.

An addition of drying oil may be discovered in a non-drying oil by a process discovered by M. Maumené and perfected by Fehling, which depends upon the much higher temperature produced by the action of oil of vitriol on the latter. Thus, when 15 grains of the following oils were mixed with 5 grains of the most concen-

trated oil of vitriol, the following rise in the temperature was observed:—

Olive oil with concentrated sulphuric acid	.	68° F.
Lucca oil " "	.	72°.5 "
Almond oil " "	.	72°.5 "
Rape oil " "	.	100° "
Poppy oil " "	.	127° "
Lucca oil with acid of 90 per cent	. .	54° "
Rape oil " "	. .	67° "
Linseed oil " "	. .	133° "

In mixtures of poppy or linseed oil with any of the others, the temperature was observed to rise in proportion to the amount of drying oil present.

The fish oils may be distinguished by the brown or black tinge which they exclusively assume when a stream of chlorine gas is passed through them.

M. Heidenreich ascertains the purity of oils by the colours which they produce when treated in small quantities on a plate of glass with 1 or 2 per cent of concentrated oil of vitriol, which process has been approved and slightly modified by M. Penot.

Thus if 10, 15, or 20 drops of the different oils be placed on a plate of glass, and a very small drop of concentrated oil of vitriol added in the middle, the following effects will be observed:—

With *rape oil* a greenish-blue ring is formed at a certain distance from the acid, and in the centre light yellow-brown streaks.

Olive oil instantly becomes pale yellow, and afterwards yellowish-green.

In *train* or *whale oil* a peculiar motion begins in the centre, and extends to the outside; then a red colour, which increases in intensity and becomes violet at the edges.

Oil of poppies and *sweet almonds* becomes of a canary-yellow colour, passing into opaque yellow.

Linseed oil yields a brown magma, becoming black.

Tallow oil or *oleine* becomes brown.

In order to judge of the purity of any specimen by this test, a comparative trial with genuine oil must be made.

Mr. Calvert finds none of these processes sufficiently delicate for detecting adulteration, and proposes a series of tests consisting of caustic soda in conjunction with sulphuric and nitric acids of three different strengths, and also phosphoric acid in the form of syrup, and *aqua regia*.

One volume of caustic soda of sp. gr. 1·340 is added to 5 volumes of the oil, and the mixture heated to the point of ebullition. This

test is principally useful to distinguish fish from animal and vegetable oils, producing with the former a distinct red colour, and detecting 1 per cent in a mixed oil.

Sulphuric acid of sp. gr. 1.475, used in the proportion of 1 vol. of acid to 5 of oil, the mixture being well shaken, and allowed to stand for fifteen minutes, gives a distinct green colour when hemp-seed or linseed oils are mixed with others to the extent of 10 per cent. The fish oils also are detected by this test, yielding a distinct red colour when contained in the proportion of 1 part in 100.

Sulphuric acid of sp. gr. 1.530, used in the same proportions as the above, but the mixture only allowed to stand five minutes, and sulphuric acid of sp. gr. 1.635 allowed to act for two minutes, were also found useful. With the latter acid, 10 per cent of rape-seed oil or of French nut oil may be detected in olive oil, or of fish oil in neat's foot oil.

Nitric acid of sp. gr. of 1.180, of 1.220, and of 1.330, used in the proportion of 1 vol. to 5 of oil, and allowed to act for five minutes, are also employed, the latter producing a fine red colour with the fish oils, poppy and French nut oils, and enabling the latter to be detected when used to the extent of 10 per cent in adulteration; and these can be further distinguished from each other by the subsequent addition of 10 volumes of a solution of caustic soda, sp. gr. 1.340, to the mixture of acid and oil.

Syrupy trihydrated phosphoric acid, agitated in the proportion of 1 part to 5 of oil, detects at once sperm, seal, or cod-liver oils, when only in the proportion of 1 to 1000 in any other oil, producing a distinct red colour.

A mixture of equal volumes sulphuric acid, sp. gr. 1.845, and nitric acid, sp. gr. 1.330, employed in the proportion of 1 to 5 of oil, and allowed to act for two minutes, enables impurities to be detected in poppy, olive, and India nut oils, which were not affected by the acids when pure.

Aqua regia, prepared by allowing 25 volumes of hydrochloric acid of sp. gr. 1.155 to stand for five hours in contact with 1 volume of nitric acid of sp. gr. 1.330, and used in the proportion of 1 volume of the acid mixture to 5 volumes of oil, and the reaction allowed to continue for five minutes, gives alone no very characteristic change; but this is brought out by the subsequent use of a solution of soda of sp. gr. 1.340, which either forms a fibrous or a fluid mass with the different oils.

The following table contains the results of Mr. Calvert's observations on the effects of these reagents upon oils, and supplies the means of detecting adulteration in a great many cases :—

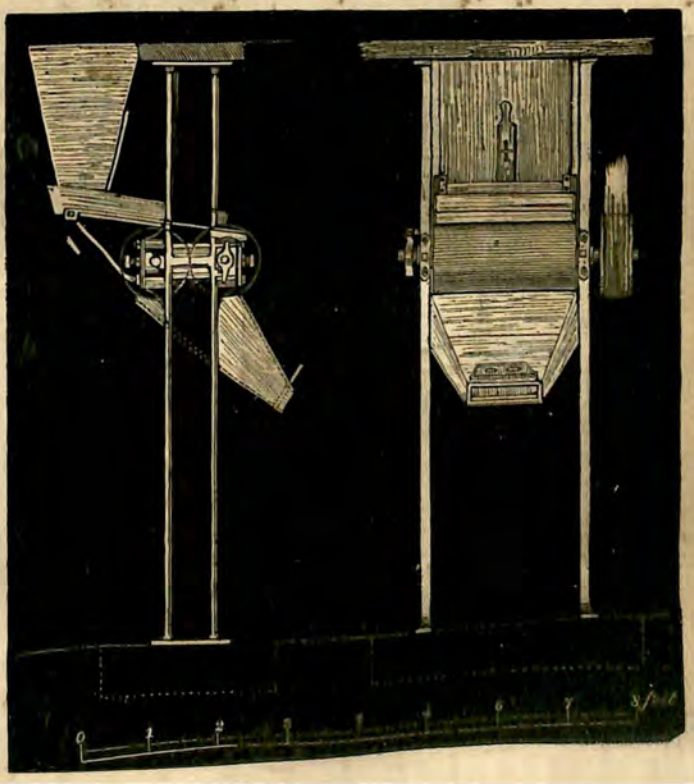
ACTION OF REAGENTS ON OILS.

OILS.	Caustic Soda, Sp. Gr. 1.340.	Sulphuric Acid, Sp.gr. 1.475.	Sulphuric Acid, Sp.gr. 1.530.	Sulphuric Acid, Sp.gr. 1.635.	Nitric Acid, Sp.gr. 1.180.	Nitric Acid, Sp.gr. 1.220.	Nitric Acid, Sp.gr. 1.330.	+ Caustic Soda, Sp.gr. 1.340.	Phosphoric Acid, syrupy.	Sulphuric Acid + Nitric Acid.	Aqua Regia.	+ Caustic Soda, Sp. gr. 1.340.
Olive	Slight yellow	Green tinge	Greenish white	Light green	Greenish	Greenish	Greenish	Fluid white mass	Slight green	Orange-yellow	....	Fluid white mass
Gallipoli	ditto	ditto	Grey	Brown	ditto	ditto	ditto	Fibrous ditto	ditto	Dark brown	....	Fibrous yellowish white mass
India Nut	Thick and white	....	Dirty white	Light brown	....	....	....	ditto	....	Orange white	....	Fibrous white mass
Pale Rapeseed	Dirty yellowish white	....	Pink	Brown	....	....	....	Fluid ditto	....	Dark brown	....	Fibrous yellowish white mass
Poppy	ditto	....	Dirty white	....	....	Orange-yellow	Red	Light-red fluid mass	....	Slight yellow	....	Fluid intense rose-coloured mass
French Nut	ditto	Brownish	Grey	Brown	Yellow	Red	Dark red	Fibrous red mass	Brown yellow	Dark brown	Yellow	Fibrous orange mass
Sesame	ditto	Green tinge	Greenish dirty white	....	Orange-yellow	ditto	ditto	Fluid red mass, with brown liquor beneath	....	Green, becoming intense red	ditto	Fluid orange mass with brown liquor beneath
Castor	White	....	Dirty white	....	....	....	....	Fibrous white mass	....	Brownish red	....	Fibrous pale rose-coloured mass
Hempseed	Thick brownish yellow	Intense green	Intense green	Intense green	Dirty green	Greenish dirty brown	Greenish dirty brown	Fibrous light brown mass	Green	Green, becoming black	Green	Fibrous light brown mass
Linseed	Fluid yellow	Green	Dirty green	Green	Yellow	Yellow	Green, becoming brown	Fluid yellow mass	Brown yellow green	ditto	Greenish yellow	Fluid orange mass
Lard	Pinkish white	Dirty white	Dirty white	Light brown	....	....	Very slight yellow	Fluid mass	....	Brown	....	Fluid pink mass
Neat's-foot	Dirty yellowish white	Yellow tinge	Brownish dirty white	Brown	Light yellow	Light yellow	Light brown	Fibrous white mass	....	Dark brown	Slight yellow	Fibrous brownish yellow mass
Sperm	Dark red	Light red	Red	Intense brown	Slight yellow	ditto	Red	Fluid mass	Dark red	ditto	ditto	Fluid orange-yellow mass
Seal	ditto	ditto	ditto	ditto	Pink	Light red	ditto	ditto	ditto	ditto	ditto	ditto
Cod-liver	ditto	Purple	Purple	ditto	....	....	ditto	ditto	ditto	ditto	Yellow	ditto

Vegetable Fats and Oils.—The vegetable fats are most abundant in the fruits, and particularly in the seeds, of plants. The olive and some other fruits, however, contain oil in the fleshy integument; and, as a rare exception, it has also been found in the root.

Rape oil; Colza oil.—Several species of the genus *Brassica*, belonging to the family *Cruciferæ*, as winter rape (*B. napus*), summer rape (*B. præcox*), common wild navew (*B. campestris*), and *Brassica napo-brassica*, contain this oil in the small, round, dry seeds, associated with mucus, albumen, and other substances. When the ground seeds are submitted to pressure, the oil, with a considerable portion of mucus and albumen, which were dissolved in the natural juices of the seed, are extracted. Fresh seed contains more mucus and albumen than old seed, and as these substances injure the quality of the oil, particularly when it is to be employed for burning, old seed is selected, dried and heated before being put in the press. The albumen of the seed is thus rendered

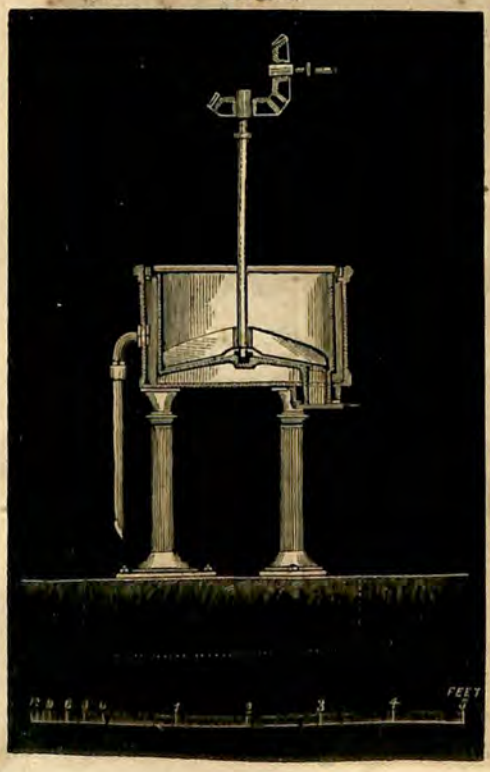
FIG. 214.



insoluble in the water; the quantity of water is also diminished by the heat, and less mucus is introduced into the oil.

In order to break the hard integument of the seed, it is first passed between cast-iron rollers, shown in Fig. 214, the distance between which can be regulated according to the size of the seed to be crushed. The rollers are sometimes of different sizes, or are so worked that different velocities may be given to their surfaces, which enables them to draw the seed in and work more rapidly. A hopper is placed above the rollers, to hold the seed, which is supplied in regular quantities. The crushed seed collects in a heap below the rollers, and is transported at once to a pair of vertical mill-stones or runners, similar to those shown in vol. ii. p. 359; these are constructed of granite, and weigh from 7 to 8 tons; they can crush from 2½ to 3 tons of seed in twelve hours. These runners are sometimes used to crush the cakes which have already been submitted to pressure, a little water being often added to old seed to facilitate the removal of the oil.

FIG. 215.

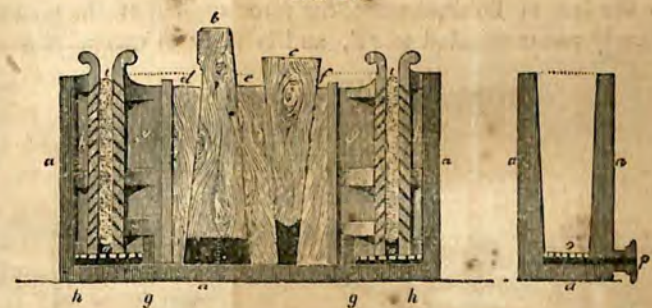


For accelerating the process, a blade revolves with the stone, for turning up the bruised seed, and detaching that which adheres to the under stone, and returning it constantly into the track of the runner. The fine flour of the seed is then heated in iron pans over an open fire, although the practice is by no means judicious, the object being to make the oil more limpid and easily expressed. When heated in pans exposed to the direct action of the fire, the seed is apt to be burned at the bottom and not sufficiently heated at the surface, notwithstanding

the constant agitation to which it is submitted by means of a stirrer worked by machinery. For this reason, steam kettles, shown in Fig. 215, are now very generally substituted for the common heaters, in which steam is admitted to the jacket of a pan containing the seed, and constantly stirred by a rouser.

The heated flour is put into woollen cloths, which are wrapped in horsehair bags and placed in the press. A powerful and continued pressure is required to express the oil which is uniformly disseminated through a great mass of seed, and the hydraulic press is now generally employed in this country; but the old Dutch mills or wedge-presses are still used both abroad and at home, and are said by some to be better adapted for the expression of oil. Mortars are sometimes used, similar to those described under Gunpowder (vol. i., first edition, p. 397), for crushing the seed, in which very heavy pestles, shod with iron, are worked by cams set in motion by a shaft turned by water or horse power; and the crushed seed, after heating, is placed in the cloths and laid between strong plates *h* and *g*, in a square space cut in a solid block of oak wood, or, as in Fig. 216, in a cast-iron case *a*. The

FIG. 216.



plates *g* and *h* are then forced together by driving in the wooden wedges which occupy the remaining space by a cam-stamp. One of these wedges, *b*, called the spring wedge, serves to loosen the apparatus; the strokes which drive in the wedge *c* tending, from the reversed position of *b*, to drive it out; *f*, *e*, and *d* are intermediate pieces to prevent the wedges from coming into immediate contact. The pressing plates are each provided with three side ribs: the immovable ones *h h* press against the sides of the case, and the movable ones *g g* against the intermediate wedges *d f*, and they are pierced with numerous holes to allow the oil to flow more easily out. On filling the press, the spring-wedge *b* must be suspended

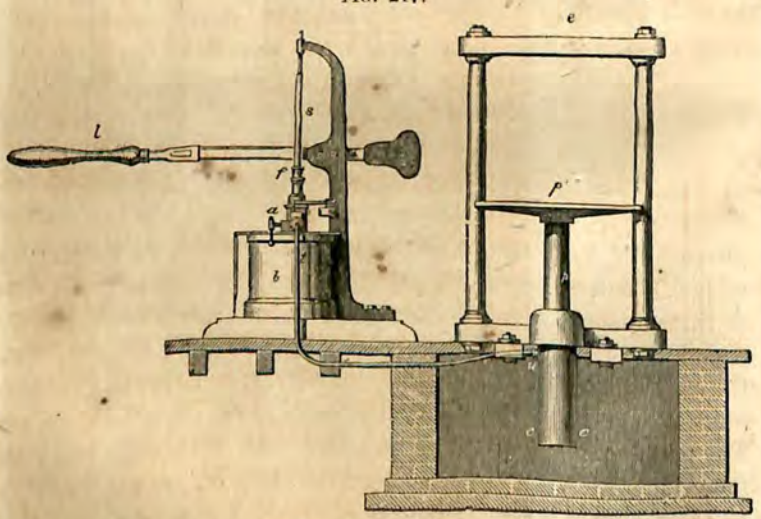
(by a rope) at a distance *a* from the bottom, that the apparatus may be easily taken to pieces. The oil trickles from the pressing plates through the pierced horizontal plates *o o*, upon which these rest, into the pipe *p*. Both *b* and *c* are driven by separate stampers, which are raised by a toothed wheel.

The weight of the stampers is usually from 500 to 600 pounds, and the height from which they fall upon the wedges from 16 to 21 inches. A press of this description can produce a pressure of 50 to 75 tons upon each cake of the following dimensions:— 8 inches in the broader base, 7 inches in the narrower, 18 inches in height, making nearly 140 square inches in surface, and about $\frac{3}{4}$ of an inch thick.

The hydraulic press is now very generally substituted in this country for these wedge-presses, as more work can be got through in the same time.

The essential parts of this machine are an ordinary draw and force-pump *a*, brought into connection with a cylinder *c c'*, by means of the tube, *t, b, u*. By working the lever *l*, water is drawn up from the reservoir *b*, and forced to *c c'*, with a power equivalent to that exerted at *l* and that of the lever together. In accordance with the law of fluid pressure, the force applied at the piston *s* is uniformly communicated to *c c'*, and is there so exerted that every

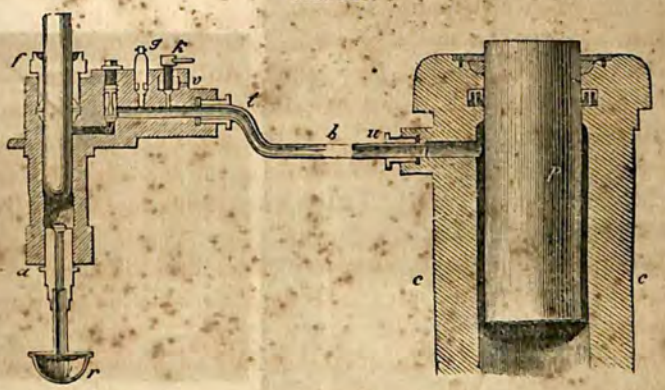
FIG. 217.



portion of the surface which equals *s* in section receives a pressure equivalent to that exerted by *s*. As this takes place in all direc-

tions, not only the sides of $c\,c'$, but also the lateral surfaces and the base of the piston p will be equally affected. The pressure on the lateral surfaces is compensated or equal on all sides, but not so

FIG. 218.



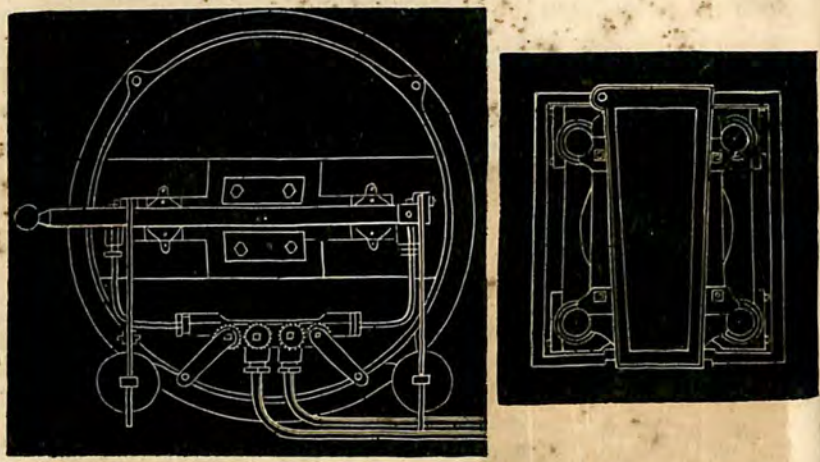
that on the bottom of the piston, the upper surface being outside the cylinder, where no opposing pressure is exerted. The piston p being movable in its stuffing box is therefore raised by a force as many times greater than that exerted by the simple pump, as the surface of the former is greater than that of the latter. A portion of this force is, however, practically lost by the very considerable friction to be overcome. The sieve r is for keeping the pump clean, g is the safety-valve, k the stop-cock, by which the machine is thrown out of gear, and the water allowed to flow off at v.

FIG. 219.

If, in a press of this kind, as it is usually employed, the smaller piston is 0.5 of a square inch in diameter, and the larger one 113 square inches, when properly worked, a pressure of 8000 cwt. may be distributed over the surface of the pressing slab. It is absolutely necessary to proceed slowly at first, and to work the press very gradually. A lesser pressure may be employed at the first by using a thicker piston, which is afterwards replaced by one of smaller diameter. The sketch at Fig. 219 shows the simple contrivance by means of which this is effected. Between the cylinder and the piston of the hand-pump is a hollow

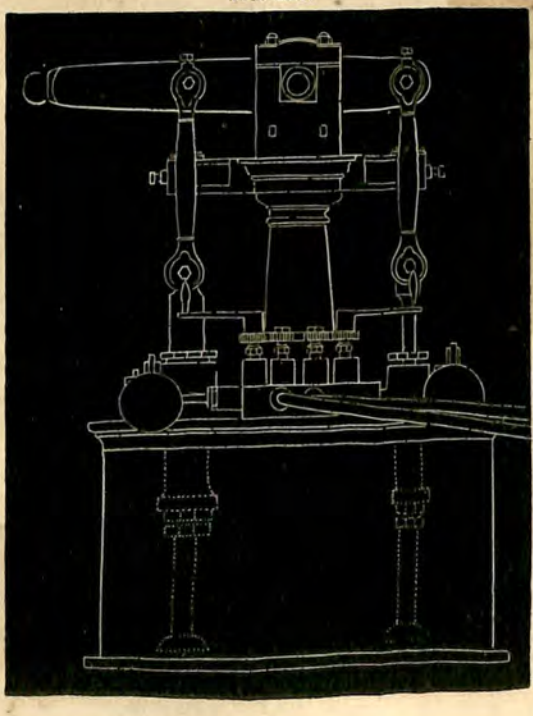
cylindrical piece *t*, which, by mere turning on the outside, may be firmly attached to the cylinder, or loosened from it, and attached

FIG. 220.



as firmly to the piston. During the working, therefore, the diameter of the piston may, as it were, be reduced from *d* to *d'*, and the pressure proportionally increased.

FIG. 221.



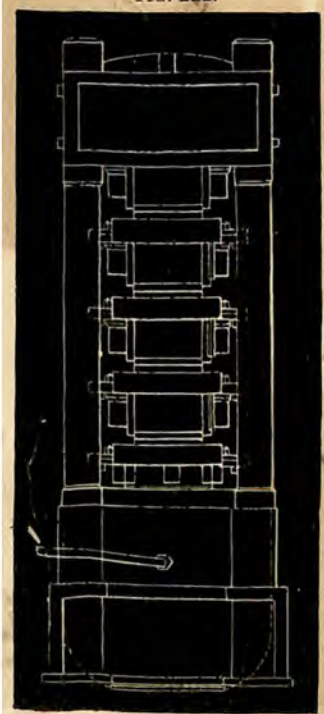
The form of press best adapted for oil works is that patented by Blundell, the ground plan and elevation of which are shown in Figs. 220, 221, and 222, of the size adapted for 4 cakes of 8 lbs. each.

The pumps, Fig. 221, are constructed of gun-

metal, and are driven from the lever by a connecting rod, at a speed of 36 strokes per minute. It requires about one-horse power to work a pair of presses. In the manufacture of rape-seed oil, the seed nearly always requires to be submitted a second time to the action of the press, and it is therefore desirable to have a pair of presses particularly adapted to the first operation, called "*clodding*."

One pair of edge stones, 7½ feet in diameter, and one pair of 13½ inch crushing rollers, will grind sufficient seed for two pairs of presses. A double seed-kettle is required for each pair, the speed of the stones being fifteen revolutions, of the rollers fifty revolutions, and of the kettles thirty-six per minute. A ten horse engine is sufficient for working the whole of the machinery.

FIG. 222.



Messrs. Bessemer and Heywood have applied the same form of press described under the article Sugar (vol. iii. p. 264) to the extraction of oils from seed. The press consists of a strong horizontal gun-metal cylinder, open at one end and closed at the other, with the exception of a small aperture, which can be increased in size as required. A gun-metal lining is fitted to the furthermost end of the cylinder, on the outside of which a spiral groove is cut, giving it the appearance of a square threaded screw. Conical holes are drilled all along the spiral groove communicating with the interior of the cylinder, which is itself also perforated with numerous holes leading to the spiral groove of the lining. Inside the lining is a bag of fustian or hair-cloth, and within this a cylinder of wire gauze or perforated metal, fitted tightly to the lining. A hopper containing the ground seed is attached to the cylinder, and communicates with it near the open end. A solid metal plunger is worked by a crank backwards and forwards in the pressing cylinder in such a manner that at each throw of the plunger a certain quantity of crushed seed falls from the hopper, and is forced forward by the plunger, the only escape

being the small aperture at the end of the cylinder. During its progress the seed is submitted to great pressure, and the oil is driven through the wire gauze, hair-cloth, and the apertures of the lining and cylinder, into a cistern placed below to receive it. It is also proposed to introduce steam into the part of the cylinder containing the seed, by which means it may be heated to the requisite temperature for allowing the oil easily to separate. The pulp or cake, which is not altogether exhausted in this apparatus, is recommended by the patentees to be submitted again to hydraulic pressure in a strong iron vessel, with water or weak alkaline ley, by which the last portions of oil can be extracted in a condition fit for the use of the soap-boiler. For the details connected with this ingenious mode of extracting oil, we must refer to the specification in the Repertory of Patent Inventions, Vol. xv. p. 91.

Brassica napus produces nearly 33, *B. rapa* only 16, *B. campestris* 39, *B. napo-brassica* 33, *B. præcox* 30, and *Madia sativa* as the mean quantity 32, or between 25 and 50 per cent of oil.

Dr. Ure gives the following as the quantities obtained in France:—

3½ lbs.	best Cambray rape seed	yielded 1	lb. of oil.
3¾ „	common rape seed	„ 1	lb. of oil.
3¼ „	poppy seed	„ 1	lb. of oil.

The oil, after leaving the press, requires to be clarified in the manner described below. Rape seed weighs 52—56 lbs. per imperial bushel.

Clarification of the oil.—The different fluid oils which occur in commerce, particularly rape oil, are by no means perfectly free from mucus and other matters of that kind which are expressed at the same time. These substances act in a very different manner to the oils during combustion: never being completely converted into gaseous products, they leave a residue of carbon, which is a serious objection to any illuminating material. Sulphuric acid is often used for clearing fat oils that are to be used for illumination in lamps. It is well known that the combustible oils do not withstand the energetic action of concentrated acids; if the action of these, however, is weakened by lessening their quantity, if only 1 to 2 per cent of sulphuric acid is used, the acid then acts chiefly upon the foreign associated matters, and very much increases the combustibility of the oil. The acid first removes the water from the mucus, by means of which it was held in sus-

pension in the oil, and then chars the mucus itself to a black mass. The oil also is somewhat acted upon: it becomes green or dark brown, and after some time deposits a sediment of the same colour, becoming then perfectly clear. Thénard first applied these facts to the purification of oils upon a large scale. It will be easily understood that the action of the acid must more or less depend upon the amount of contact between the two fluids, and upon the temperature. At a temperature of 60° to 70° C. (140° F. to 158° F.) the quantity of acid may be reduced to ½ per cent.

Some manufacturers employ agitating vessels, or machinery for mixing the acid and oil, in connection with subsiding tanks. From 1 to 1½ per cent of sulphuric acid is gradually added in a thin stream, with constant agitation to the oil previously heated. The same quantity of steam (at 100° C.) which will raise 1 part of water 60° C. will raise 3.2 parts of oil to the same temperature, in consequence of their different specific heats. When, after continued agitation, the dark-coloured oil in the tubs is evidently composed of a clear fluid with suspended flocculent matter, the action of the acid is finished, and warm water of 60° (140° F.) (⅔ of the oil) is added, keeping up the agitation to separate the acid as much as possible and prevent the metallic vessels from being acted upon in the subsequent employment of the oil. The water, intended to separate the acid, collects, after standing for several days, under the black flocculent matter at the bottom of the depositing tubs. The clear oil above both, however carefully it may be drawn off, must always be filtered before becoming cold, and for this purpose vats are used with conical openings in the bottom stopped with cotton plugs. Baskets lined with moss or cotton answer the same purpose. The filtration is always a difficult operation, the plugholes becoming constantly and quickly stopped.

The idea which has been patented by Lienau, of attaching a pump to the lower part of the filtering apparatus, the barrel of which rises up by the outside of the filtering-vat, might perhaps be of service in this operation, the suction of the pump drawing the oil more rapidly through the porous material of the filter.

It is desirable to use milk of lime, and a current of steam to remove the last portions of acid, though not often practised. Other methods of clarification, like that proposed by Watt, in which oxidizing substances are used as chromic acid, and that of Cogen by means of a solution of potash, have not been generally adopted. On the whole, clarified oil is not much less coloured than crude oil,

and according to Brandes almond oil only, and not the combustible oils, can be decolorized by the most powerful means, as animal charcoal.

M. Cassgrand recommend a prolonged contact of steam as a means of purifying oils, tallow, and wax. The oils and melted solid fats are caused to pass through a serpentine tube together with steam, by which means a large surface is exposed to the contact of the steam. The oils are thus deprived of their disagreeable smell, and, when allowed to stand, a deposit is formed below the clear and nearly colourless oil.

Humfrey has patented a process for passing nitrous gas through oleine or oils in such a manner that the deutoxide of nitrogen resulting from the deoxidation of the nitrous gas can again be converted into peroxide by mixture with air. The resulting oxidized fat is washed with a solution of common salt, containing a small quantity of caustic alkali, and then allowed to crystallize as usual. In this manner a substance adapted for making candles is said to be obtained, and an oil resembling sperm oil in properties.

Olive Oil.—The olive tree *(Olea europæa)* belonging to the family *Jasminaceæ,* produces a stone-fruit, the fleshy greenish-brown integument of which contains an oil that exceeds all other vegetable oils in sweetness, and in the property of being readily saponified. The olive tree is a native of Asia, but has long been cultivated and grows luxuriantly in southern Europe, particularly in Greece, southern Italy, and Spain. It is not very unlike the English willow, and often attains a great size, beginning to bear fruit when five years old, and continuing productive for a century, or sometimes for a considerably longer time. The more common kinds of olive oil only, which are unfit for the table and not required for soap, are used for burning. Although the fruit is very juicy as compared with oil seed, yet a certain turgidity of the tissue, and the hardness of the stone (which is not removed in the first instance, as it would involve a loss of time), offer no inconsiderable resistance to the press. For the production of salad oil of the best quality, the carefully collected crop should be put under the press as quickly as possible, yet a practice which has been handed down by tradition is still much followed, and found advantageous; it consists in allowing a certain amount of fermentation to proceed in a mass of fruit heaped up in storehouses, which kills the olives, softens them, and causes them to part more easily with a larger quantity of oil. This fermentation becomes perceptible by the heat that is generated, which

must not be allowed to exceed 36° (96° F.), in a layer several inches thick, without injury to the quality of the oil. If the temperature has risen too high, and the juice which flows out is brown and decomposed, as is often the case, the oil is always of very inferior quality. The slightly fermented fruit is first bruised into a soft dough in fruit-mills with upright stones, collected in rush sacks, which, to the number of eighteen or twenty at a time, are placed under a kind of wine-press. The press is gradually tightened, time being given for a portion of oil to run out between each turn of the screw. The product of this first pressing is the finest or *virgin oil*. What remains in the cake will not flow off of itself. The press is, therefore, taken apart, the cake broken up in the bags, and the nearly dry residue digested with hot water, and again put under the press as before: this operation is repeated two or three times. For the reception of the mixture of water and oil two tanks are used, in one of which the liquids separate into two layers, whilst the other is filling. The upper layer consisting of oil is taken off with scoops; the water below, which still contains oil and mucus in suspension, is collected in cisterns for further separation, the water being after some time removed by a long syphon. The oil from a larger quantity of press-water than the cistern can properly hold, is allowed to collect in it, by drawing off the lower water which is free from oil, before the whole quantity is admitted. When a sufficient quantity of oil swims on the top, it is skimmed off as oil of second quality. The growers of oil find that the residue after the second pressure still affords so much oil of inferior quality as to make it worth while to submit it to a third operation. The crushed cake from the press is stirred up with a large quantity of water, so as to become quite muddy. The broken stones fall to the bottom, while the soft kernels come to the surface, from whence they are collected with hair sieves, and dried over a fire until they form a stiff paste, which is then submitted to the third pressure.

All the varieties of oil remain about twenty days in a warm place (not under 20° C., 68° F.) in casks or tanks, where they deposit mucus before being shipped for market.

Gallipoli is one of the principal ports whence olive oil is exported to the more northern parts of Europe. Extensive oil-tanks are constructed in the rock on which this port is built, in which the crude oils are collected, according to their different qualities, as they arrive in skins from the interior. The quality of the oil is much improved by being allowed to remain some time in these reservoirs

where it becomes quite clear and bright by depositing mucus. A full crop of oil from the neighbourhood of Gallipoli amounted in 1843 to nearly 22,000 tuns. Olive oil has a light yellow, or sometimes a greenish colour; it begins to deposit stearine a little above the freezing point of water, and at 22° F. as much as 28 per cent of the weight of the oil separates in the solid form. A large quantity of olive oil is exported from Spain, where the manufacture is said to have been much improved by the introduction of the hydraulic press, by which the operation of pressing can be done in a shorter time, and the quality of the oil not impaired by the fermentative process.

Olive oil is very frequently adulterated with rape, cocoa-nut, poppy seed, and gingelly or sesame oil, and Poutet's method is said to be the best for testing its purity. 5½ oz. of mercury are dissolved at a gentle heat in 4 oz. of nitric acid, and 7 oz. of water added when the solution is perfect. One part of this solution of nitrate of mercury is added to 2 parts of oil in a bottle ⅔ths filled with the mixture, and well shaken for three or four minutes; again shaken after some time, and then allowed to stand for some hours. If the oil is genuine, the whole becomes solid; if it contain 5 per cent of any of the other oils, it remains fluid.

Madia Oil.—The plant from which this oil is obtained, *Madia sativa,* belonging to the syngenesious family, originally indigenous to Chili, has lately been successfully introduced into Germany. The oil is obtained as from other dry seeds, in the manner which has been described, but it must be remarked that sweet salad oil, for which purpose Madia oil may be used, should always be prepared in the cold. The oil has a golden-yellow colour.

Palm Oil.—Palm oil is a vegetable fat, extracted from the fruit of a kind of palm, *Avoira Elais,* or *Elais guianensis,* and according to others from *Cocus butyracea.* These palms are the produce of the tropical parts of Africa south of Fernando Po, and the oil is brought to Europe from the west coast of that continent, being extensively used in the manufacture of soap and candles. Although the existence of palm oil has long been known, it was always classed among the curious products of nature, and not among those substances which are of importance in the arts, until by a remarkable concurrence of circumstances, intimately connected with the humane efforts of the British legislature for the suppression of the slave trade, the importation of this substance has become an important branch of commerce. Since the slave

trade has been subjected to the restrictions of the English, the natives of the coast, instead of bartering human beings, have been forced to substitute the useful produce of the soil, or palm oil. As many as twenty slave ships were to be found at the mouth of the Bony river (an arm of the Niger) until the blockade of the English put a stop to the traffic, and made an opening for the exportation of palm oil to the amount of 20,000 to 25,000 tons yearly. The great consumption of this oil is in England, where two hundred times as much is consumed as in France; the palm oil used in the latter country amounting to only ½ per cent of the fats saponified.

The fruit of the palm is of the size and form of a pigeon's egg, of a golden yellow colour, and contains a hard stone, surrounded by a fleshy integument. The oil is obtained from the latter, not from the stone. The fleshy part is bruised and boiled with water, when the oil separates on the top, and can easily be collected. On cooling, it assumes the appearance of a reddish-yellow fat, of the consistence of firm butter, melting when fresh at 81° F., but, after being kept for some time, at 90° to 96° F. The term oil being generally applied to the liquid fats, this substance should properly be called *palm butter*. It has a strong but agreeably aromatic smell, very much resembling that of the violet root. Palm oil, as it occurs in commerce, is in that state in which the ordinary fats are called rancid; it contains free fatty acids. The amount of these free acids increases with the age of the oil, and its fusing point rises at the same time. Pelouze and Boudet found in fresh palm oil one-third of the weight to consist of free acids, one-half in oil which melted at 31° (88° F.), and in a specimen which fused at 36° (96½° F.) four-fifths of its weight. Stenhouse found the fusing point of very old palm oil to be at 37° (99° F.) The researches of Frémy, and the other chemists named above, have shown that this vegetable fat contains free oleic acid, a peculiar fatty acid, *palmitic acid* ($C_{32}\,H_{31}\,O_3 + HO$), also in the free state, free hydrated oxide of glyceryle, and *palmitine* (palmitate of oxide of glyceryle = $C_{32}\,H_{31}\,O_3 + C_3\,H_4\,O$*), which varies in quantity with the age of the oil, amounting in fresh oil to two-thirds of its weight. Palmitine can be obtained as a white wax-like mass by pressing palm

* The researches of Redtenbacher upon Acroleine ($C_6\,H_8\,O_2$) tend to show that hydrated oxide of glyceryle, which is intimately related to the former, must be considered as $2\,C_3\,H_4\,O + 4\,HO$, instead of $C_6\,H_7\,O_5 + H$, which is the constitution usually assigned it.

oil in large quantities at a temperature of from 10° to 12° (50°—54° F.), and a second time at about 24° (75° F.) : it is then used for preparing a kind of stearine candles, whilst the fluid yellow oil is saponified.* This separation is, however, seldom effected before saponification. The cause of the rapid decomposition (becoming rancid) of palm oil, which occurs so much more readily in this than in the other oils, has not been satisfactorily explained. It is remarkable also that the quantity of hydrated oxide of glyceryle diminishes in very old palm oil in consequence of this rancidity.

Bleaching of Palm Oil.—The yellowish-red colouring matter of palm oil is not destroyed by the process of saponification, and where the acids are to be employed for the manufacture of candles or soap, and distillation is not employed, the bleaching of the oil becomes a matter of importance. The colouring matter may be destroyed by the action of chlorine, oxygen, powerful acids, or simply by heat and light.

Davidson's process consists in melting the palm oil in an iron vessel, lined with lead, with the addition of from 6 to 11 per cent of chloride of lime, previously stirred up with 12 parts of water. When the ingredients have been thoroughly mixed, and the whole has become cold, it is cut into small pieces, and exposed to the air for two or three weeks. The chlorine liberated from the chloride of lime by the carbonic acid of the atmosphere then gradually bleaches the oil. The lime is separated from the oil at the expiration of this time, by melting it with dilute sulphuric acid, until the sulphate of lime is deposited at the bottom of the vessel, and the oil swims on the surface of the liquid. The sulphuric acid evolves the remainder of the chlorine, and completes the process of bleaching. The same result is obtained when chlorine is evolved in contact with the melted oil by the agency of manganese, common salt, and sulphuric acid. The only objection to the use of chlorine is, that it attacks the oil itself at a higher temperature, decomposing the palmitic acid with ease, and taking the place of the hydrogen in the acid. All excess of chlorine,

* It appears from the experiments of Schwartz, that palmitic acid, which melts at 60° (140° F.), is converted, on exposure to the air, at a temperature of 250° to 300° (514° to 572° F.), with the simultaneous formation of carbonic acid and water, into a new acid, the palmitonic, which fuses at 53° (127° F.), and that the latter acid is frequently the substance contained in the candles prepared from palm oil.—*Annalen der Chemie und Pharmacie*, lx. 58.

therefore, which can never be avoided, impairs the quality of the fat. When palm oil is melted over a dilute solution of nitric acid, or a weak solution of saltpetre, and sulphuric acid is slowly added, the oil is rapidly bleached, but not in a permanent manner; for when mixed subsequently with the lye in the boiling pan for making soap, the colour again appears. The colouring matter of palm oil is destroyed by sulphuric acid, added in the proportion of 4 per cent to the melting oil, just as the mucus was destroyed by the same agent in rape-seed oil.

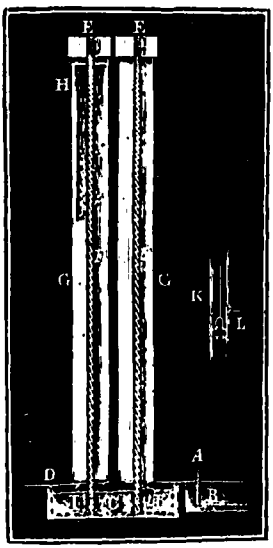
The use of oxygen for bleaching, derived from sulphuric acid and manganese, was first introduced by Michaëlis. He mixes palm oil with one-sixteenth of finely-powdered manganese, adds to the mixture half its weight of boiling water, and with constant agitation slowly pours concentrated sulphuric acid, to the amount of one thirty-second of the weight of the oil, upon the mixture; the mass is then allowed to cool. The solidified fat is of a greenish hue, but becomes white in a short time by the action of air and light. This plan is said to harden the product.

Zier first observed that palm oil slowly poured over a heated iron plate absorbs oxygen from the air, with the evolution of an acid vapour, and becomes converted into a clear colourless fat. In England, this observation has been applied upon a large scale. At first the crude palm oil was heated, 40 or 60 cwts. at a time, in cast-iron boilers, to the high temperature of 232° C. (450° F.) But before the whole mass could attain this temperature, the bottom of the boiler was often heated to 300° C. (572° F.), giving rise to an intolerable smell from the evolution of vapours, blackening and charring the oil, and not unfrequently causing explosions. As soon, however, as it was discovered that the decomposition of the colouring matter began at a temperature of 110° C. (230° F.), the decolorization has been carried on at that temperature, although with a greater expenditure of time. When the melted oil has attained 110° (230° F.) over the open fire, the heat is kept up by the introduction of a current of high pressure steam (15 lbs. pressure to the square inch) during the whole operation, and the decomposition is promoted by constant stirring. Ten hours are required for the decolorization of 4 tons of palm oil.

Zier's observation has been carried into practice in the following manner with great advantage. The apparatus (Fig. 223) consists of

a large steam-pipe open at A, over which the bung-hole of the cask is inverted, and as the oil melts it runs out into the cistern B, where any sediment is allowed to deposit. It is then syphoned off into another cistern C, where it is kept in a liquid state by the steam-pipe D. The melted oil is pumped into the cisterns E E by the pumps F F. The bottoms of these cisterns are pierced with a number of small holes, through which the oil flows down the shafts G G, in a shower of small streams, as shown at H, into the cistern C, at I I. The oil is pumped up again, and heated in the manner described until perfectly free from colour.

FIG. 223.



The pumps are enclosed in a copper pipe, as shown at K, between which and the shaft of the pump a jet of steam is admitted at L.

The whole apparatus is constructed of copper, as tin will not resist the action of the acid in the palm oil.

The cost of this method is very small, being only the wear and tear and the expense of the fuel for raising the steam.

When the oil is exposed to the joint action of air and light, assisted by a high temperature, it is very rapidly bleached, and this plan has almost entirely superseded the others. Several very large square or flat boxes, or cisterns, are prepared, which may either be constructed simply of wood, and are still better when lined with lead. These boxes are 12 inches deep, and are furnished at the bottom with a serpentine leaden tube, in connection with a steam boiler. Into these cisterns, which must be so situated as to admit of the free access of air and light, after they have been filled to the height of 8 inches with water, palm oil is introduced in sufficient quantity to form a layer of two inches after being melted by the admission of the steam. The current of steam must be regulated so as to afford a uniform temperature of 212° F. At the expiration of ten or fifteen hours the colour is destroyed; the length of time required depending very much upon the power of the sun's rays. Payen found that the destruction of the colour

was not impeded by covering the cisterns with glazed frames, but in such a manner that the air continued to have free access. It is probable that palm oil might be bleached with great advantage by the tropical sun of Africa, before its importation into Europe. A slight yellowish hue cannot be removed from the oil even by the most perfect process of bleaching, which, on cooling, gives it a dirty-white appearance; this, however, is no longer perceptible in the soap that is made from it.

The most complete, most rapid, but at the same time the most costly method of removing the colour is that introduced by Watt, who uses bichromate of potash and strong mineral acids. Watt's process is, therefore, an oxidation of the colouring matter by chromic acid. Palm oil is melted and allowed to stand, when it deposits the suspended impurities mechanically. The clear oil is drawn off into wooden vessels, mixed with a concentrated solution of 25 lbs. bichromate of potash, 8 lbs. oil of vitriol, and about 50 lbs. of strong muriatic acid to the ton of oil, and the whole is well stirred together. Instead of muriatic acid, common salt, with an appropriate addition to the quantity of sulphuric acid, may be used. In a few minutes, the mass having been well stirred, the light green appearance of the oil, and the rising of a thick scum to the surface, indicate the completion of the process. It can easily be seen by the colour of specimens allowed to cool, whether a sufficient quantity of the bleaching material has been used. The chemical decomposition attending this process of bleaching is easily understood. The sulphuric acid combines with the potash, and liberates the chromic acid, which, parting with the half of its oxygen to destroy the colouring matter, becomes converted into oxide of chromium, which combines with the muriatic acid to form soluble chloride of chromium. The bleached oil has now to be separated from the aqueous solution of chloride of chromium (and of sulphate of soda, when common salt was used). This separates as the heavier liquid, upon which the oil swims, when the warm mixture is allowed to stand quietly for half an hour. The fat collected from the surface is then washed in a second vessel with water heated to the boiling point by a current of steam. The process of bleaching the above quantity, 20 cwts., is finished in about five minutes.

The cost of bleaching by Watt's method is estimated as follows: About half a ton is operated upon at a time, and the temperature of the oil is maintained at about 100° F.

	s.	d.
10 lbs. bichromate of potash . .	6	8
10 „ common salt . . .	0	0
15 „ oil of vitriol . . .	1	7
	8s.	3d.

Or about 16*s.* 6*d.* per ton.

The oil employed in the manufacture of candles is now generally saponified with vitriol and distilled at a high temperature, in the manner described below.

Oil of Illipa (*Ilpa and Epei oil*).—This oil very much resembles palm oil, both as regards its origin and nature, but it is much less known in commerce. It is said to be obtained by pressure from the fruit or seeds of trees growing on the coast of Coromandel and Bengal, which the natives call Makwah or Mawy, and which are considered by the botanists Roxburgh and Hamilton to be the *Bassia latifolia* and *longifolia*, species belonging to the family of the *Lapoteæ* (order *Sapotaceæ*, Lind.) The fruit has the form of a lengthened olive. A single Makwah tree, though growing in the most sterile mountainous districts, is said to produce 2 tons of fruit, affording 60 lbs. of oil yearly. According to Henry, the oil is not extracted by pressing, but by boiling with water. It is of a light greenish-yellow colour, has an aromatic smell, resembling olive oil or cocoa butter, and is solid at moderate temperatures, its melting point being 22°—23° (72°—73½° F.) At 28° (82½° F.) it forms a lemon-yellow liquid, from which reddish brown flocks like tannin are deposited. In alcohol it is but slightly soluble. Its taste is at first mild, becoming gradually more and more acrid, from rancidity, to which it is very subject. Pelouze and Boudet found this fat to consist of olcine and stearine.

In India the oil is employed for the manufacture of soap, and for burning in lamps; and in Great Britain, for the manufacture of candles. The species of *Bassia* are remarkable for supplying at the same time saccharine matter, spirit, and oil which is used both for food and burning. The butter obtained from *Bassia butyracea* is a white solid fat fusible at about 120°, very little disposed to rancidity, and employed for adulterating butter.

Galam Butter.—Galam or *Shea butter*, also the produce of a species of Bassia (*Bassia Parkii*), but indigenous to the interior of Africa, is so similar to palm oil, that it is often confounded with it. It has a greater resemblance, however, to tallow, and is more solid

than Illipa oil; its smell and taste are not so piquante, and it has a dirty yellow colour. It forms a permanently turbid oil when melted. As the product of rancidity, Galam butter contains free acid, and free oxide of glyceryle. It is solid at 97° F.

Cocoa-nut Oil.—More important than the two vegetable fats just described is the so-called *cocoa-nut oil* or *cocoa butter*, a white rancid fat, as it is imported, of the consistence of hog's-lard, but lamellar in texture, and possessing a disagreeable smell. It is extracted, according to existing statements, from the kernels of the cocoa palm (*Cocos nucifera* and *butyracea*), either by pressure or by boiling. This palm is indigenous to the two Indian peninsulas, viz. the coasts, chiefly, of Malabar and Bengal, as well as to Ceylon, the Maldives, and Siam; it is also abundantly found in the Brazils. The whole Brazilian coast from the river San Francisco to the bar of Mamamguape, a distance of 280 miles, is almost entirely covered with it.

The cocoa palm grows to the height of 60 or 90 feet, the stem is soft and fibrous, and marked with rings, occasioned by the fall of the leaves, two of which are said to drop off every year. From 11 to 12 leaves, each 12 or 14 feet long, form a tuft at the top. The flowers proceed from within a large pointed spathe, which opens on the under side. In wet seasons the tree blossoms every five or six weeks, so that there are often fresh flowers and ripe nuts on the tree at the same time. There are 5 to 15 nuts in a bunch, and in good soils a tree may produce from 8 to 12 bunches every year.* The kernels of the cocoa palm, called *Copperah*, in commerce, are now brought to Europe, and the oil is extracted by the aid of heat, the kernels having been previously ground or cut into small pieces. Tindall, in working upon 420 lbs. of copperah in portions of 7 lbs. each, obtained different kinds of oil by pressing the fruit in sacks and mats made of the cocoa-nut fibre, every increase of temperature raising the melting point of the extracted oil. The whole having been divided into five portions, each of which was treated at a higher temperature than the preceding, the following results were obtained:—

* Tomlinson's Cyclopædia, where a copious account of the other numerous industrial uses of the different parts of this valuable tree will be found, taken from the "Memoirs of the Wernerian Natural History Society."

1st portion	85¾ lbs.	pressed at a	temperature	of from	14° to 15° C.	(57½° to 59° F.)
2nd „	13⅜ „	„	„	„	18° to 19° C.	(65° to 67° F.)
3rd „	21¼ „	„	„	„	24°	(75⅛° F.)
4th „	26¾ „	„	„	„	29° to 30° C.	(84½° to 86° F.)
5th „	91¼ „	„	„	„	40° to 41° C.	(104° to 106° F.)
Together,	238⅜ lbs.					

The cake which remained weighed 155 lbs.; the difference, 26⅜ lbs., was chiefly oil, which ran down the sides of the press, and was collected in a separate vessel. Thus it appears that the kernels contain 60 per cent or more of oil, in all probability consisting of two varieties, a fluid and solid fat, which are distinct and separate in the seeds, but become mixed under the press, and the more the higher the temperature is raised, so that fluid or solid fat, or such as possesses a medium consistence, may be obtained at pleasure. In the above experiments, indeed, the first and second portions were quite liquid and transparent; the third was semi-transparent and milky; the fourth solid, and of a dirty white colour; the fifth was of a pure white colour, and very firm. 10 nuts are said to afford about a quart of oil, according to some statements, others only give 3 lbs. of pure oil for 32 nuts. The cocoa-nut oil that is prepared in Bengal is said to be better than that from Ceylon. The melting point of the commercial oil is about 20° (68° F.), which is probably the temperature at which it is extracted. In Ceylon the oil is used for burning in lamps, which are made from a section of the shell of the nut, and used with a cotton wick. Torches are also prepared by soaking elephants' dung in cocoa-nut oil, and then covering the mass with long dry leaves, tied at short distances with shreds of bamboo. The oil is also used for anointing the body, and for ointments and salves. The quantity of cocoa-nut oil imported in 1850 was 98,040 cwts.; in 1851, 55,994 cwts. Pelouze and Boudet considered the solid fat to contain elaidic acid,* until Brandes and Bromeis proved this substance to be a combination of a peculiar fatty acid, cocoic or cocostearic acid ($C_{27}H_{52}O_3$) with oxide of glyceryle (cocine). In the rancid oil of the cocoa nut this acid is partly free, or in the form of hydrate ($C_{27}H_{52}O_3 + Aq.$)

Numerous other plants afford fatty substances, the nature of which has been little studied, few being known to European commerce. The following are some of the more important, to

* The acid which is formed by the action of nitrous acid on the liquid fat oil.

which attention was prominently drawn by the specimens exhibited in 1851:

Gingely oil is obtained from the seeds of *Sesamum orientale*, and varies very much in quality from the crude mode of its preparation, but is said to be equal to olive oil in purity when carefully extracted. The seeds afford 45 per cent of oil. The seeds of the *Margosa* tree also afford lamp oil.

Ram-til oil, obtained from the seed of the *Guizotia oleifera*, a plant introduced from Abyssinia and common in Bengal, is extensively used for burning in lamps. The seeds yield about 34 per cent of oil.

Ground nut oil, from the seed of the Bhoemoong, or *Arachis hypogœa*, extensively cultivated in some parts of India, is also used for burning. The seeds yield 44 per cent of oil.

Napala oil, from the seeds of *Jatropha curcas* and *Mulu oil*, from the *Argemone mexicana*, are also used in India.

Vegetable Butters and Wax.—Several varieties of solid fat are obtained in the Indian Archipelago from the seeds of different species of *Dipterocarpus*. The *Kawan* is a hard, yellowish-green coloured substance, brittle, and fusible at about 93° F., and when fused solidifies at about 86°; it is the produce, probably, of the tallow tree of Java, supposed by some to be a species of Bassia. A white solid oil, fusible at 97°, is obtained from the fruit of the dammar or doop-tree, *Valeria indica*, a large and quick-growing tree in Malabar and Canara. This oil, when distilled in the manner now practised with palm oil, is said to afford an excellent material for candles, superior to that from cocoa-nut oil, which produces suffocating acrid vapours when the candles prepared from it are snuffed out.

Cocum oil, obtained from the seeds of *Garcinia purpurea*, is a white, or pale greenish yellow, solid oil, brittle, or rather friable, having a faint, but not unpleasant smell, melting at about 95°, and when cold after fusion remaining liquid at 75° F.

Kali-ziri, or *Khatzum*, is obtained from the seed of *Vernonia anthelmintica*, fusible at 95°, and easily bleached.

Neem oil is obtained from a species of Margosa, *Melia azadirachta*: it is pale yellow, and solid at ordinary temperatures.

Gutta podah, a bright green-coloured wax, and the *Myrtle*, or *berry wax*, from the Cape of Good Hope, are excellent materials for the manufacture of candles.

A vegetable butter called *crab* or *carapa oil*, is obtained from

British Guiana, as the produce of the seed of *Carapa guianensis*, or *Xyloearpus carapa*, which is a large tree abundant in the forests of Guiana.

Myrtle or *berry-wax* is the produce of different species of *Myrica*. At the Cape of Good Hope it is obtained from *Myrica cordifolia*, and in Louisiana from the *Myrica cerifera*, as an incrustation on the berries. By boiling the berries with water, a hard brittle wax, of a pale green colour, is removed, having a specific gravity of 1.015, and melting at 110° F.

Palm wax is secreted from the stems and leaves of palm trees, and imported from Rio de Janeiro. It is soluble in boiling alcohol and ether, and fuses at about 160° F.

Cerosine or *sugar-cane wax* is obtained from a hard and ligneous variety of the sugar-cane. It fuses at 180° F., is soluble in boiling alcohol, but sparingly soluble in boiling ether.

Vegetable Tallow of China.—This white sebaceous substance is found enveloping the seeds in the capsules or nuts of *Stillingia sebifera*, a tree cultivated in several provinces of China. The nuts are pounded in a mortar to loosen the seeds, they are then steamed in tubs with convex open wicker bottoms, placed over cauldrons of boiling water; when thoroughly heated, they are reduced to a mash in a mortar, and thence transferred to bamboo sieves kept at a uniform temperature over hot ashes. This operation of steaming and sifting is repeated, as the first does not deprive the seeds of all their tallow. The article thus obtained becomes a solid mass on falling through the sieve, and, to purify it, it is melted and formed into cakes for the press; these receive their form from bamboo hoops a foot in diameter and three inches deep, which are laid on the ground over a little straw. On being filled with the hot liquid, the ends of the straw beneath are drawn up and spread over the top, and, when of sufficient consistence, are placed with their rings in the press. This apparatus is of the rudest description, constructed of two large beams placed horizontally so as to form a trough capable of containing about fifty of the rings with their sebaceous cakes; at one end it is closed, and at the other adapted for receiving wedges, which are successively driven into it by ponderous sledge-hammers wielded by athletic men. The tallow oozes in a melted state into a receptacle below, where it cools. It is again melted, and poured into tubs smeared with mud to prevent its adhering. It is now marketable, in masses of about eighty pounds each, hard, brittle, white, opaque, tasteless, and with-

out the odour of animal tallow; under high pressure it scarcely stains bibulous paper; it melts at 104° F. It may be regarded as nearly pure stearine; the slight difference is doubtless owing to the admixture of oil expressed from the seed in the process just described. The seeds yield about 8 per cent of tallow, which sells for about 5 cents per pound.

The process for pressing the oil (*elaine*), which is carried on at the same time, is as follows:—This is contained in the kernel of the nut, the sebaceous matter which lies between the shell and the husk having been removed in the manner described. The kernel, and the husk covering it, are ground between two stones, which are heated to prevent clogging from the still adhering sebaceous matter. The mass is then placed in a winnowing machine, when, the chaff being separated, the white oleaginous kernels, after being steamed, are placed in a mill to be mashed. This machine is formed of a circular stone groove, in which a solid stone wheel revolves perpendicularly, being driven by the aid of an ox. Under this ponderous weight the seeds are reduced to a mealy state, steamed in the tubs, formed into cakes, and pressed by wedges in the manner already described; the process of mashing, steaming, and pressing being also repeated with the kernels. The kernels yield about 30 per cent of the oil, which is called "Tsing-yu," and sells for about 3 cents per pound, and answers well for lamps, though inferior for this purpose to some other vegetable oils in use. The cakes which remain after the oil has been pressed out are much valued as a manure, particularly for tobacco-fields, the soil of which is rapidly impoverished by the Virginian weed.

Vegetable Tallow Candles.—The consumption of candles in China is very great, as the gods cannot be worshipped acceptably without candles, and no one ventures out after dark without a lantern. These candles are made, with few exceptions, by dipping a wick in the tallow or stearine of the *Stillingia sebifera*. The wicks are made of rush, coiled round the stem of a coarse grass, and when of the required diameter, they receive a final dip in a mixture of the same material, and "insect-wax" (*vide* Wax), by which their consistence is preserved in the hottest weather. They are generally coloured red by a minute quantity of Akanet root (*Anchusa tinctoria*, brought from Shangtung). Verdigris is employed to dye them green. Stearine candles cost about 8 cents per pound in China.*

Train oil.—A fleet of ships, bearing all colours, annually sails

* Hooker's Journal of Botany.

to the Polar Seas upon the whale fishery, the object being partly the whalebone, but chiefly the blubber of the fish, which produces a fluid fat, train oil. Seals and dolphins are captured for the same purpose.

The east shores of Greenland, Davis' Straits, and the interior of Baffin's Bay, are the seats of the whale fishery in the northern hemisphere. South Australia and New Zealand send vessels to the Southern Ocean for the same object. The *Balæna mysticetus* affords the largest amount of oil which is contained in the blubber or cutaneous fat enveloping the entire body. It is also sought for the whalebone it affords. The sperm or white whale (*cachalot*) *Physeter macrocephalus*, affords much less oil, but a quantity of spermaceti in the cavities of the head. The whales are taken with the harpoon, and dispatched with steel spears: the superficial blubber, the whalebone, and the jaw-bones, which are full of oil, being removed, the carcase or kreng is cast adrift. A large whale will yield 20 tons of rendered oil, which, with the other products, may be worth nearly £1000.

The blubber is packed in casks, and carried to the sea-ports to be melted out. An incipient decomposition of the animal matters and of the fluids attached to the blubber takes place during the voyage, which, although it aids the melting, occasions the formation of a peculiar fat, composed of oxide of glyceryl in combination with an acid long considered peculiar to this oil, and called *phocenic acid*, but since shown by Dumas to be identical with valerianic acid. The nauseous odour which accompanies all train oil is due to the formation of this fat. The cellular tissue of the blubber becomes thus so disintegrated, that the oil runs off by itself, when the whole is put into casks with wire-work bottoms, over tanks for holding the oil. The train oil is heated to 100° (212° F.), that the impurities in suspension may the more easily separate; and the clear oil, after having stood for some time, is drawn off from the thick portion.

On the western coast of Ireland, the basking shark (*Squalus maximus*) is sometimes taken in considerable quantities in the spring of the year, the blubber of which affords a large quantity of very excellent oil. If carefully rendered by melting over a slow fire, or by steam heat, the oil is of a light amber colour with very little smell, nearly the whole of which it loses by exposure to the air and light. This oil is equal to sperm oil as an illuminating agent, and may be employed in lamps constructed for the consumption of sperm.

In train oil, the impurity is not mucus, but animal gelatine or glue, and besides this, volatile stinking matters. Some use a solution of tannin for clarifying it, which forms with the gelatine insoluble flakes; others employ metallic salts, as blue vitriol, or sugar of lead, which act in a similar manner. The nauseous odour is best removed by bleaching powder.

In order to confer a greater degree of fluidity upon the common whale oils, and thus render them more suitable for burning and better lubricators, Hutchison proposes to mix them with oleic ether, which communicates this property to them.

Seal oil.—The production of seal oil, according to J. S. Archibald, quoted in Dr. Ure's Dictionary, is one of the most important branches of industry in Newfoundland, as many as 367 vessels, of 35,760 tons, employing 13,000 men, having been occupied in the capture of from half to three-quarters of a million seals in the year 1852.

The *pelts* of the seal, consisting of the skin and fat which surround the whole body, are removed while the animal is warm; the carcase, being of no value, is left upon the ice, where the animals are captured. The pelts are allowed to cool on deck, and then stowed away in the hold; in this state they reach the shipping ports, the principal of which is St. John's. The species captured in greatest number are the young of the hood and harp seals. The skins are separated from the fat by hand, and after being dry-salted for about a month, are shipped to Europe.

The fat is placed at once, without further preparation, in the seal-vats. These consist of a strong wooden erection, called a crib, from 20 to 30 feet square and 20 to 25 feet in height, firmly secured with iron clamps, and the interstices between the upright posts filled with small round holes. The crib has a strong wooden floor, capable of sustaining 300 or 400 tons. The crib stands in a wooden pan, 3 or 4 feet larger than the square of the crib, and 3 feet deep, intended to catch all the drippings. The cribs are divided generally into nine compartments or pounds. The fat is thrown into these vats so as to fill them, and the oil gradually oozes out at the side apertures without the aid of any additional pressure than that of the mass itself. The first runnings are of the best quality, clear, and with little smell; they are termed *pale seal oil*, and at the end of two or three months from 50 to 70 per cent of the whole produce has been thus obtained. Decomposition then sets in, and the fat of the old seals, which is tough,

becomes disintegrated, and yields oil which gradually deepens in colour and has a most offensive smell. When this ceases to run, the mass of fat in the vats, which has now become quite putrid, requires to be turned. The contents of the one vat are now thrown into another, so that what were the uppermost portions lie at the bottom, and are subjected to the greatest pressure. When the brown oil thus obtained has ceased running, the contents of the vats are boiled in large iron vessels, with any other portions of the pelts which had not been added to the contents of the vats; and the produce is called *boiled seal oil.* The operations last altogether about six months, during which time, and particularly in the warm season, they disseminate a most insufferable odour throughout the neighbourhood. Mr. Archibald has patented a process for rendering seal oil by artificial steam heat, the details of which he does not communicate, but by which the whole operation may be finished in about twelve hours, and a uniform pale seal oil obtained from both old and young seal fat. It will easily be understood that the quality of the produce can never be other than stinking and deep-coloured from so very crude a process as that now prevalent in Newfoundland.

Tallow.—In the animal body there exists a peculiar skin-like tissue, filling up the interstices between the different organs, and surrounding them in all directions: it is called *cellular tissue.* In certain places in the caul, for instance, the single cells formed by thin membranous walls are the chief depositories of animal fat, which, in the form of globules or small drops, swims in the animal fluid with which the cells are filled.

Melting and Purification of Tallow.—In ruminating animals the firm and, at ordinary temperatures, solid nature of the fat is characteristic; oxen, stags, sheep and goats, all furnish tallow, although not of equally good quality. From the scarcity of the other kinds, ox tallow was until recently alone used as a source of light; but Australia now exports to Europe a large quantity of mutton tallow. As far as their application is concerned, these fats are alike in properties, and the more solid the tallow, the more it is esteemed for illuminating purposes. Dry ripe fodder has been found by experience to increase the firmness of the fat, while it is soft in animals fed upon grains. Hence the tallow which comes from Russia, where the animals are fed for eight months upon dry fodder, is generally superior to that produced at home. The object of melting out the tallow is to unite the globules into one mass by

separating them from the cells; for candles, certain parts are preferred, namely those round the caul, and in the neighbourhood of the heart, the kidneys, and of the intestines. Formerly tallow was universally rendered by the agency of heat alone, the fat being cut up into small pieces and melted in a pan over an open fire; and this plan is still very general, although the temperature must exceed that of boiling water if the whole quantity is to be obtained. The cells are first burst by the expansion of their fluid contents; a milky liquid is formed, which becomes clear by degrees, as the water contained in the cells, or which in some cases is added in small quantities, evaporates. The heat is now increased until the particles of skin, having lost all their water, appear hard and somewhat baked, and no longer yield any fat. At this period the heat is moderated so as to leave the fat in a fluid state at the top; this is strained and poured out into blocks; the residue, baked a second time and pressed, furnishes a second portion, of inferior quality, and generally coloured. The residue, called greaves or cracklings, is used for feeding dogs. As a maximum product, which is seldom actually attained, beef suet yields 95 per cent of tallow and 2 per cent of refuse, mutton suet 91 per cent and 4.5 per cent of refuse; in the latter there generally remains a considerable quantity of tallow, amounting often to 8 or 10 per cent.

There are several objections to this method of rendering; the cells are imperfectly destroyed, and become so hard that they do not readily part with the tallow under the press. It is also impossible to keep up a uniform heat; at the bottom of the vessel it rises too high, and injures the colour and quality of the tallow, while the fat becomes softer and more fusible, and takes up copper from the sides of the vessel. Lastly, during the process of melting the animal matters evolve inflammable, and consequently dangerous, gases and vapours, which also possess such an intolerably nauseous odour that long habit alone enables the workmen to support them. The use of steam alone, instead of an open fire, is but a partial remedy, the temperature being too low; and by conveying the steam directly into the fat, the membranous substance becomes rapidly converted into glue, which is then difficult to remove. Mechanical power, which has been applied in some places, is superior to other plans; the cells are either torn or crushed by upright millstones or in mortars, and when this is once effected, it

is only necessary to obtain the requisite temperature, and the tallow separates perfectly fluid.

Darcet, by an excellent method, employs chemical means to produce the same result. Weak sulphuric acid is made to act upon the tallow, which destroying and breaking up the cells chemically, also combines the advantage of preventing, with careful management, the evolution of the stinking vapours, or at least of rendering them much more tolerable than under ordinary circumstances. His plan is to melt the crude tallow with one-half its weight of water, which has been previously acidified with 3.3 per cent of sulphuric acid, and to retain this at the boiling temperature until the separation of cellular and fatty matter is complete. Although the inventor proposed his plan for working with an open fire, yet the separation is so much aided by the presence of the acid, that a steam temperature is sufficient to complete the process. In Taulet's apparatus steam heat is applied from without; in Champy's, steam is admitted to the melting mass, by which means the cellular matter is made so porous as to be easily pressed, or, by a second boiling, parts with the whole of its tallow. Experiments with the former apparatus produced from 2 to 4 per cent more than were obtained with an open fire; with respect to the immediate introduction of steam, it has been found practically better to use less water with a greater amount of acid (about $\frac{1}{5}$ of the weight of the tallow and 6 per cent of acid), as the condensation of the vapour then establishes about the right proportion.

Lefebure recommends the tallow to be macerated three or four days in an acid bath, and then to be melted in a fresh bath.

The greater part of the tallow of commerce is prepared with so little care, that it cannot be used by the candle-makers without being remelted and purified. They call this operation *clarification*, or *rendering*. The operation consists simply in remelting the tallow with some clarifying substances, which are everywhere different, and consist of the most heterogeneous salts, such as vitriol, saltpetre, sal-ammoniac, common salt, alum, Epsom salt, glass skimmings, &c. These are intended either to render insoluble, residuary portions of gelatine or glue, or to convert the water into a specifically heavier liquid, which then subsides more easily with the impurities.

Darcet has proposed to carry off the stinking vapours, which

cannot be entirely avoided in all these operations, by a strong draught into the chimney, or to conduct them to the hearth, and thus render them innoxious to the workmen. The hood and conducting pipe, with which the copper must then be supplied, unfortunately obstruct the process.

The use of acid not only affords a larger produce, but has another very great advantage in making the tallow harder and more sonorous.

Tallow Candles.—Candles are cylindrical or slightly conical rods, formed of solid fat, enclosing a bundle of parallel or twisted fibres of cotton, called the wick, through which the melted fat is drawn up to the region of combustion. It is in this form that the solid fats are employed for giving light, and as the preparation of the candles is generally, if not always, associated with the manufacture or purification of the material composing them, we shall describe under each class of substances the mode in which it is converted into candles, reserving for a future page a few remarks on the history of candles and the theory of their combustion.

The wicks employed for the best candles are composed of cotton rovings, imported from Turkey. In common candles the wick is formed of parallel fibres, and the glycerine which is present in tallow and pressed tallow (stearine) candles being much less combustible than the fatty acids, always produces a carbonaceous snuff at the end of the wick, which can only be removed either with snuffers or by causing the wick to curl towards the edge of the flame, where, meeting with the current of air, it is wholly consumed. By plaiting the wick in the braiding machine it acquires the property of curling, and as the level of the tallow sinks, the upper end of the wick, where the snuff collects, comes into contact with the air at the edge of the flame. This is practised with the wicks for stearic acid, spermaceti, and wax candles, which are also generally impregnated with a solution of some salt, such as borax (formerly sulphuric acid was used), which melts at the temperature of the edge of the flame, combining with the ash of the wick, and drops off in the form of a small bead. Tallow, however, from its greater fusibility, is very apt to gutter when the wick is thus made to curl to the one side, unless prevented by being confined in a cap, as in Palmer's candle-lamps.

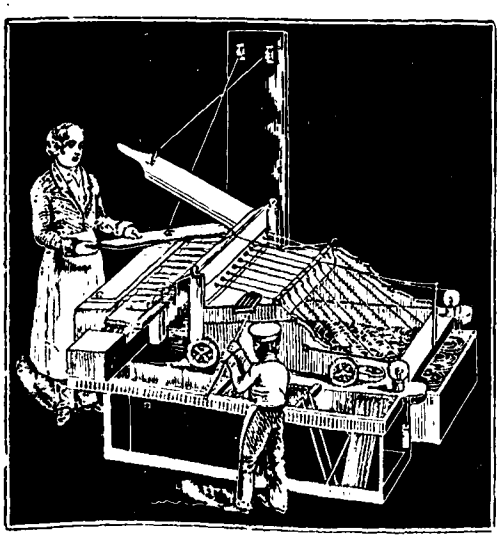
In Palmer's tallow candles, which require no snuffing, one thread of the wick is first impregnated with subnitrate of bismuth ground up with oil, the whole is then bound round in the manner

called gimping; one, two, or more of these wicks are then wound round a thin rod in a spiral manner, and placed in the centre of the mould, which is then filled with tallow; when the tallow cools the rod is withdrawn. On burning these candles, the wicks uncurl, and form so many separate flames, and the ends, coming into contact with the air at the edge of the flame, are consumed.

William Palmer heats the wicks and expels moisture by immersing them in oil or candle-stuff to about 300° or 350° F., when, being impregnated with fat, they are no longer liable to absorb moisture; and if during this process the wicks are wound round a cylindrical rod in a spiral manner, and straightened before the imbibed fat has become quite solid, they will retain the tendency to uncurl during the combustion of the candle in which they are subsequently enclosed.

The wicks for dip-candles are often cut by machinery in a very expeditious manner, and the wood-cut, Fig. 224, will help to explain how this is effected. Balls of cotton, previously made into loose roving or cord, consisting of a dozen or more threads each, but differing in thickness according to the size of the candles, are put into a box or drawer. The ends of these are then attached to a rod or broach, and equal lengths of cotton are cut off by drawing a knife along a whole range of them at once; a slight twist being given them by the action of the machine.

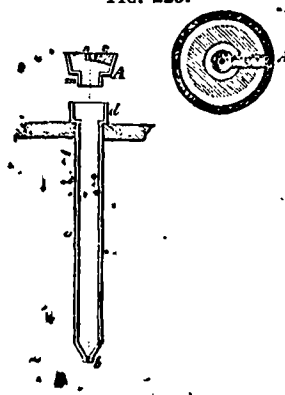
FIG. 224.



Tallow candles of the cheapest kind are made by repeatedly dipping the wick into the melted fat; they are then called *dips*, to distinguish them from those made with *moulds*. Mould candles are cast in cylindrical pewter vessels of the exact shape of the candle, Fig. 225, slightly tapering towards the wick end *b*,

and carefully polished inside. These vessels have sometimes been constructed of glass, and Field has proposed longitudinal moulds, made of earthenware or similar material. A number of these moulds are arranged in holes in a frame made for the purpose; they rest upon shoulders somewhat below the upper orifice, with the pointed end downwards. The wick is inserted through the aperture *b*, where it serves as a stopper, and is fastened at the top to the vessel *A*, which forms a distinct part of the mould, and consists of a movable top, fitting exactly into the tube at *d* with its narrower part *m*. From a point in the margin *c*, a piece *e* is soldered in the direction of the radius with a round opening or eye *n*, so that the two orifices for the wick, *n* and *b*, are exactly opposite to each other, and the wick itself is thus brought exactly into the middle of the mould. The upper end of the wick (or the lower in the candle) is previously saturated with tallow to give it more consistence. When the little vessel *A* is not used, as with the glass moulds, a peg is put through the end of the wick formed into a loop, and rested upon the end of the mould, whilst the wick is pulled tight from below. Candles are sometimes made in which there is no visible wick at the bottom; a wick somewhat shorter than the mould is then used, and is kept tight in the first instance by a looped thread, which is afterwards withdrawn.

FIG. 225.



It is essential in moulding that the tallow should completely fill the mould, which is kept in a perpendicular position; that the candle should remain entire on cooling, without cracks, and should be easily removed from the mould. These conditions can, however, only be attained when the fatty particles at the sides cool more quickly than those in the interior; and, indeed, the whole candle should be rapidly cooled, to prevent contraction. A cool season of the year is preferable for moulding; but a certain condition of the tallow, namely that which it possesses at a temperature very near its melting point, is absolutely necessary. The candle-makers recognise the proper consistence of the tallow for moulding by the appearance of a scum upon the surface, which forms in hot weather between 44° (111° F.) and 48° (119° F.), in mild weather

at 42° (108° F.), and in cold at about 40° (104° F.) The tallow is usually melted by itself; sometimes, however, over a solution of alum. The filling is generally done with a small can, but much better with a tinned iron syphon. The candles cannot be easily taken out of the moulds until the day after casting, they are then cut and trimmed at the base, and when the little capsules are used the whole portion with which they are filled is removed.

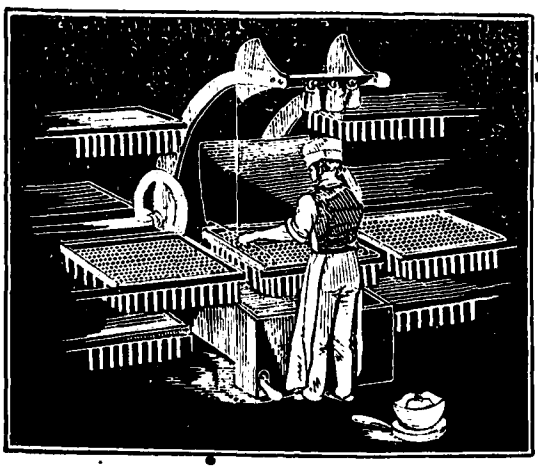
In the process of *dipping*, two vessels are used, one for melting a supply, the other containing tallow in the proper condition for dipping. The wicks, according as six or eight candles are to go to the pound, are hung side by side on a wooden rod or *broach*, sixteen or eighteen together. That the broaches may be set aside conveniently and without interruption during the operation, in the same order in which they have been dipped, a frame of laths (*the port*) is placed handy over a flat tray to collect the droppings. The first part of the operation is to saturate the wicks with hot tallow, cold tallow not penetrating sufficiently into the fibres of the wick. The saturated wicks are rounded and smoothed, either in the palm of the hand or upon a flat board, and taken lastly from the port in the same order in which they were saturated, and dipped a broach at a time. The dipping is done by a quick, steady motion of the hand, only to be acquired by practice; having been once dipped in the melted tallow of the proper temperature, the dips are placed again upon the port, and the operation is repeated until the candle has acquired the proper thickness. By a more or less deep immersion in the tallow, and particularly at last, when the candles are left so long immersed that the lower part may be melted off, the natural tendency of the tallow to collect in too thick a layer below is obviated, and the candles assume a cylindrical form. In some places the wicks are attached to the edge of small discs, which are arranged on the periphery of a wheel movable upon a perpendicular axis, so that, as the wheel is turned, the discs are successively brought above the vessel containing the melted tallow, and can be detached for immersion. A warm piece of iron, with a round hole to suit the size of the candles, aids in giving them their regular form.

The operation of dipping candles is also performed very rapidly by a machine similar to that represented in Fig. 226, each broach being supplied with a number of wicks in the manner described above: thirty of these broaches are ranged side by side, and then

constitute what is technically termed a *frame*. From thirty to forty of these frames may be suspended on the same machine, which thus supports many thousands of candles at once.

A vessel of melted tallow is placed in front of each machine, and the frames are brought one after the other immediately above it, and dipped. By means of a lever, moved by the foot, a wiping-board is lowered after each dipping, which removes the excess of tallow from the lower ends of the candles. A kind of steelyard, to which each frame is in turn attached, indicates the successive increase of weight, and enables the workman to ascertain when the candles have been dipped a sufficient number of times, after which they are set aside to harden and dry.

FIG. 226.



Although the process of dipping is much more laborious and troublesome than moulding, yet it admits of inferior kinds of tallow being employed for the inner parts, whilst the best is used for the outer. Candles improve by keeping, becoming better and harder; when freshly prepared, they often have a yellow colour, but can always be bleached by exposure to the air.

Stearine.—Among the proximate constituents of tallow, as they were investigated and separated by Chevreul, some were found possessing a much higher melting point than the original tallow, and were firmer, dryer, and even brittle; in other respects they were quite analogous to fat, but had ceased to feel greasy and to stain, and possessed those properties in the highest degree which manufacturers have endeavoured to confer upon tallow by the different modes of hardening, and which render it more similar to wax. For a long time two of these constituents have been articles of manufacture, under the common name of *stearine;* they are, however, chemically quite distinct, and bear the same

relation to each other as a salt bears to its constituent acid. One only of these substances is called in scientific language *stearine*, and has already been noticed (page 389); the other is *stearic acid*. Stearine alone was at one time the object of manufacture; but this has of late years given place to the production of stearic acid.

Melted tallow is completely dissolved by eight times its weight of ether; on cooling, the *oleine* only remains dissolved, with a very little *stearine*, which almost entirely crystallizes, and can be completely purified by washing with ether. Stearine is a solid, pulverable substance, does not stain, and is translucent, like alabaster. Its production on a large scale is not so much an absolute separation of stearine from oleine, as an augmentation of the quantity of stearine in tallow, which in its natural state contains about $\frac{2}{3}$ of its weight of stearine. The method actually practised is very simple. Completely fluid and transparent melted tallow is allowed to cool as gradually as possible, with constant agitation, to about 38° C. (100° F.) At this temperature, the stearine only has become solid in the form of numerous small crystals, which, swimming in the fluid portion, thicken the whole into a whitish turbid pasty mass: this is then placed in cloths and slowly pressed in the hydraulic machine already described, during which operation the greater part of the oleine is imbibed by the woollen cloths. By repeating the operation, a solid cake of stearine is obtained, of greater purity after each repetition of the process.

Centrifugal machines, known more generally as hydro-extractors, modifications of which were described in vol. iii. p. 327, under the article Sugar, have also been employed for separating the more solid from the liquid fats, the temperature of the room and the filtering material being adapted to the substance operated upon.

The observations made by Liebig and Pelouze upon stearine render it highly probable that it must be considered a salt of two bases, as is now generally admitted. Water plays the part of one base, while the other is the oxide of a compound radical glyceryle ($C_6 H_7$) with 5 atoms of oxygen, which is contained in most fats, and is known in the form of a hydrate $C_6 H_7 O_5 + HO$. The acid of the salt has many of the properties of a fat, and outwardly resembles stearine: it is *stearic acid*. In a similar manner, oleine is a salt of an oily, fluid, fatty acid—of oleic acid, with the same bases. Besides oleic and stearic acids, the researches of Heintz have shown that palmitic acid is a large constituent of many kinds of tallow, and that the margarine supposed to form the chief

ingredient in mutton suet is, in fact, a mixture of 1 part stearine and 10 parts palmitine. Stearic acid, as known to manufacturers, is consequently a mixture, in variable proportions, of stearic and palmitic acids; and tallow must be considered chemically as a mixture of peculiar double salts of the fatty acids with water and the oxide of glyceryle.

The fluid part of mutton suet is composed of oleine, with a small proportion of another liquid fat, which yields an acid on saponification having a lower atomic weight than oleic acid.

Chevreul's discovery of the constitution of the fats, which was the germ whence the present processes for the manufacture of stearic acid have sprung, was many years before it was brought into practical application. The original experiments were published in 1823, and in 1825 Chevreul and Gay-Lussac took out a most comprehensive patent for the manufacture of fatty acids, comprising nearly all the processes which have since been actually adopted. The plan of operation at first proposed was, however, found too expensive: although lime was specified as one of the saponifying agents, soda and potash were employed, and hydrochloric, in place of sulphuric acid, was used for decomposing the soaps.

In the hands of De Milly, who, in 1831, first successfully substituted lime for the alkalies in the process of saponification, the manufacture of the fatty acids made most important progress. About the same time, the imperfect combustion of the cotton wicks, which materially impeded the consumption of candles made from these materials, was remedied by soaking them in borate, phosphate, or sulphate of ammonia. There still, however, remained several difficulties to be overcome in the production of these bodies, so as to render them suitable for the manufacture of candles, among which the large grain or size of the crystals was the chief, as it prevented a uniform consistence throughout the substance of the candle. Arsenious acid, when mixed with the stearic acid in very small quantities, was found to prevent the crystallization, and was at first used for this purpose; but as the fumes of this substance were necessarily given off during combustion, and are highly poisonous, its use could not be tolerated. A very small proportion of wax was then found to answer as well; or by simply heating the moulds to the melting temperature of the acids, and stirring the liquid fats during congelation, the formation of large crystals is entirely avoided.

Stearic acid. Saponification by Lime.—The principle upon which the separation of stearic acid is founded, is the displacement of the oxide of glyceryle by a powerful mineral base, such as lime. The resulting mixture of stearate and oleate of lime is decomposed by the addition of sulphuric acid into sulphate of lime, and a solution of stearic in oleic acid, which by crystallization and pressure are separated from each other.

The first process consists in the saponification of the fatty acids by lime, which must be as pure as possible, and properly slaked. The stearate, margarate, and oleate of lime are solids, and remain, while the glycerine, being set at liberty, dissolves in the water.

In a wooden vat lined with lead, 9 or 10 cwt. of tallow are melted with about 200 gals. of water, by means of a perforated steam pipe, and 140 lbs. of quick lime in about 120 gals. of water are added, care being taken to keep the mass thoroughly agitated.

In about seven hours the liquid containing the glycerine may be run off, and the hard lime-soap removed. In some manufactories the sulphuric acid is used in this stage of the operation.

The lime-soap is broken up, reduced to powder, and sifted. In this state it is thrown into another vat, of similar construction to the previous one, and heated with the necessary quantity of dilute sulphuric acid. In about three hours the decomposition is complete, and on cooling the sulphate of lime has fallen to the bottom, while the fatty acids float on the surface of an acid liquid.

The fatty acids are drawn off into a similar vat, and washed with very dilute sulphuric acid in order to remove the last traces of sulphate of lime. A second washing with pure water in another vat completes this part of the process. All the washings are made at a high temperature by means of steam.

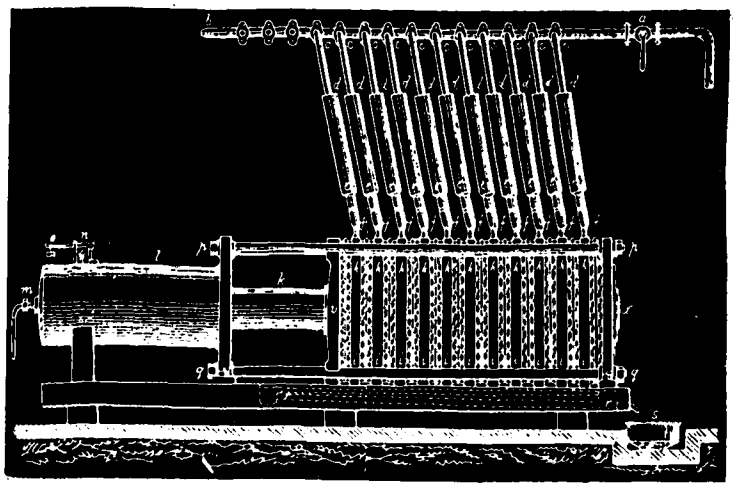
Formerly the fatty acids were allowed to solidify in square blocks of ½ cwt. each, which required to be cut up into shavings before being put under the press. This was done by a cutting machine similar to a chaff-cutter, the blocks being screwed forward to meet a series of knife-blades attached to a wheel, which cut off shavings of uniform thickness.

The fatty acids, purified as described above, are now drawn off into shallow conical moulds made of tin-plate, from which, when crystallized, they are easily removed and enveloped in a coarse cloth. In this state they are placed on the tray of an hydraulic press, with thick plates of zinc interposed here and there, until the pile is about 3 feet high. The press is worked very gently at first,

and a considerable portion of the oleic acid is removed even at the ordinary temperature of the air.

It is necessary, however, to employ a press of peculiar construction, similar to that in use in some oil-mills, in order to remove the last traces of oleic acid with the aid of heat. In Fig. 227, when

FIG. 227.



the cock *a* is opened, the tube *a b* is filled with steam, which passes through the tubes *c d e f*, and the body of the plates *h i*. Each plate may be used separately, by means of the two joints at *c* and *f*, while the tubes themselves may be lengthened as they move to the right or left of the perpendicular. A section at Fig. 228 explains how this is accomplished by means of the piston which terminates the tube *c d* entering the large tube *d e*. The elevation, Fig. 229, also illustrates how the joints *c* and *f* allow the plate *h i* to take an horizontal movement in connection with the telescopic tube *c d*.

In Fig. 230 may be seen how the steam passes through the body of the plate by means of a winding tube, while Fig. 231 shows the position of a cake of fatty acids enveloped in horsehair cloth, terminating in two points at *j*.

A simpler form of horizontal hotpress is used in some factories, in which a perforated steam-pipe is carried along the bottom of the press, through which, when the press is in action, steam can be at once admitted to the interior. When the cakes and the solid plates have been introduced, the whole is covered with a lid, and steam

FIG. 228.

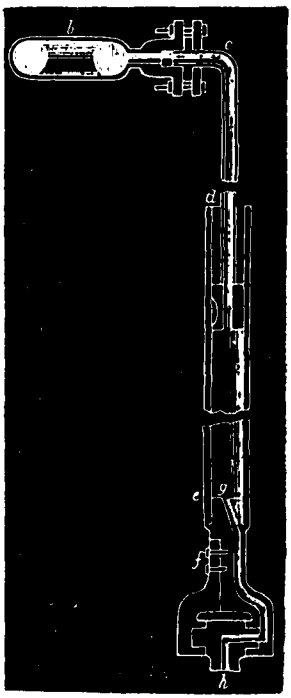
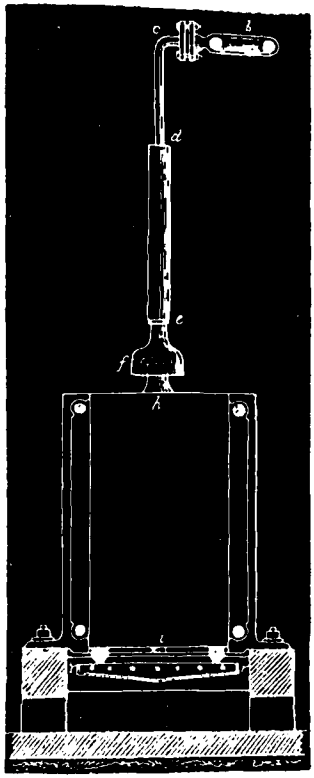
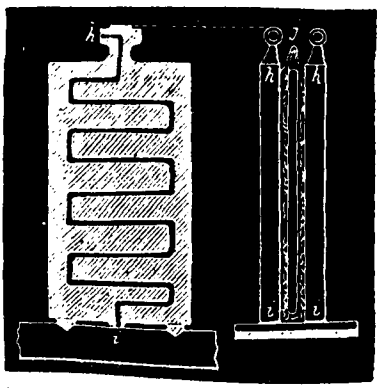


FIG. 229.



blown in, which keeps up the requisite temperature. This plan is said to answer extremely well, and the apparatus being very much less complicated, is considerably cheaper.

FIG. 230. FIG. 231.



The liquid fats which are expressed escape by the pipe *r r* (Fig. 227) and collect in the vessel *s*, from whence they are removed to a special cistern. The oleic acid always carries off a portion of stearic acid in consequence of the increased heat, but this again crystallizes as the temperature falls.

The oleic acid is removed to a

great extent by these two operations, and the cakes of the solid fatty acids are exposed to the air and light for the purpose of being bleached.

These cakes are then treated with very dilute sulphuric acid in a commodious vat, so as to remove the last traces of lime, and afterwards washed two or three times with water. Finally, they are removed to another vat heated by steam, clarified by means of white of egg, and run into moulds.

Stearic Acid Candles.—The purified fatty acids are melted in a copper heated by steam, 3 to 5 per cent of wax being added, to give greater firmness to the candles and prevent the formation of large crystals. The moulds are precisely similar to those in common use for tallow candles, except the upper part, or funnel, which is larger, to allow the air to escape. The mould frame most generally used contains thirty forms, Figs. 232 and 233.

FIG. 232.

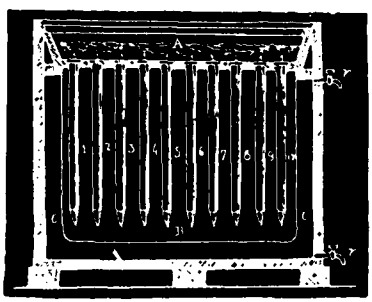
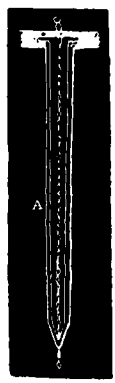


FIG. 233.



The wick is first dipped in a solution of boracic acid, which uniting with the potash, lime, &c., in the ashes of the wick, forms a fusible glass, which may be seen in the form of brilliant globules on the extremities of the wick. It is then stretched and slightly twisted, and kept in the axis of the mould by little brass screws or pegs. The object of the twisting is to avoid the necessity of snuffing the wick, for when the wick is left at liberty by the melting and burning of the stearine, its fibres unfold themselves outwardly beyond the edge of the flame, and are thus gradually consumed by the oxygen of the air.

The moulds thus furnished with wicks are placed in a tin vessel, A B, Fig. 232, which is formed with a double case *c c*.

A temperature of 100° C. (212° F.) is maintained by means of a jet of steam, the two stop-cocks *r r'* being used for the escape of the air and condensed water.

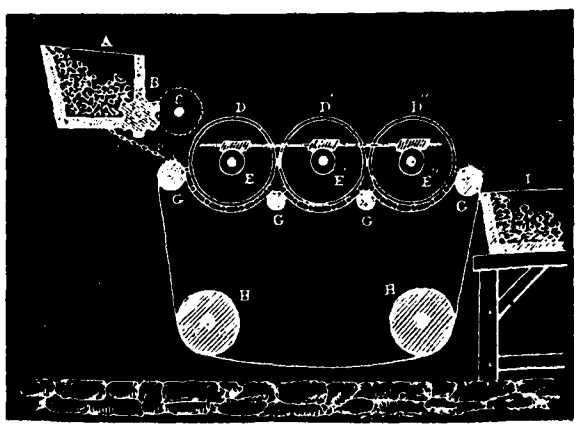
When the moulds have cooled down to 45°. C (113° F.) the stearic acid, previously melted, is poured into them. It is necessary to employ these precautions to allow the fatty acid to fill the moulds completely before crystallization takes place. The candles are removed with the ordinary means and precautions when sufficiently cold.

The candles are also exposed to the action of the air and moisture, to allow the surfaces to undergo a process of bleaching and improve their appearance.

They are then washed in a weak solution of carbonate of soda, to remove all dust and other impurities, placed on a linen sheet, and subjected to gentle pressure under a cushion of linen, which dries up the moisture and communicates a degree of polish.

The last operations are the cutting and polishing, which are performed by the following machine, shown in Fig. 234. The

FIG. 234.



candles are arranged in order in a hopper A. A fluted cylinder B receives them one by one, and as it turns round presents them to the revolving saw *c*, which cuts the ends smooth, and allows them to fall upon an endless woollen cloth belt, supported by the small rollers G G G, and passing round the large drums H H. Three other cylinders, D D' D'', covered with woollen cloth, are put in motion in a contrary direction by the three pinions E E' E'', and being fixed in a movable frame they receive a second alternating motion in the line of their axis. The last roller delivers

them into a vessel I, perfectly smooth, and with a fine polish, produced by the friction which they have received during their passage from the saw *c* to the last roller G.

Many manufacturers stamp their candles, the impression being given as the candle is taken from the receiver, previous to packing. This is done to ensure a genuine article, as an imitation candle is prepared, composed of common tallow, with a coating of stearine.

The oleic acid is manufactured into an inferior soap in some localities, and employed in the preparation of woollen goods, for which latter purpose it is necessary that all the solid acids should be removed by crystallization in the cold.

Moinier and Boutigny's Process.—The following is the process of Moinier and Boutigny for the preparation of stearic acid and stearic candles by the aid of sulphurous acid :—

At present the produce of fatty acids never exceeds 92·3 per cent of the tallow employed, which is increased to 96.8 per cent by this improvement.

It is an acknowledged fact, that saponification may be equally well effected by acids and bases, while in certain cases sulphurous acid converts oleine into elaidine. It was therefore supposed that the sulphurous acid aided in some way the action of the lime generally employed. It has been found, however, by experiment, that the sulphite of lime formed, when decomposed by the sulphuric acid, yielded sulphurous acid, which destroyed the nitrous acid compounds dissolved in the chamber acid, and which now act upon the fatty acids, thus occasioning the difference in the produce noticed above. The beneficial action of the sulphurous acid during saponification is therefore clear.

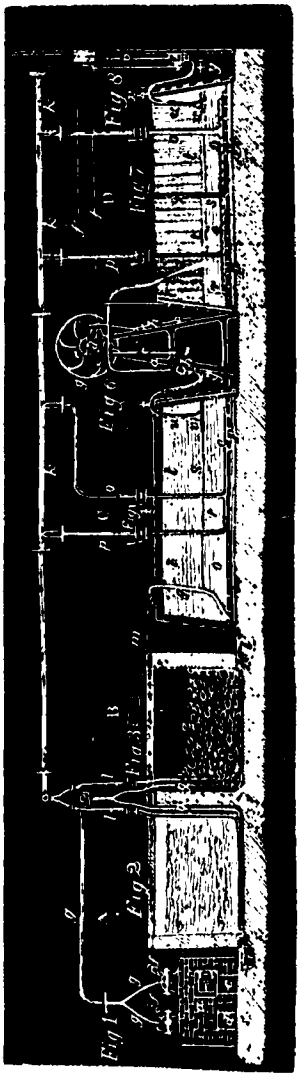
The operations are conducted in the following manner in this manufactory, which turns out about 57 tons of stearine and candles, and 47 tons of oleic acid, per month.

Two tons of tallow and 900 gals. water are introduced into a large rectangular vat, of about 270 cubic feet capacity. The tallow is melted by means of steam admitted through a pipe coiled round the bottom, and the whole kept at the boiling point for an hour, during which a current of sulphurous acid is forced in. At the end of this period 6 cwt. of lime, made into a milk with 350 gals. water, are added. The mixture soon acquires some consistence, and becomes frothy and very viscid. The whole is now agitated, in order to regulate the ebullition and prevent the sudden swelling up of the soapy materials. The pasty appearance of the

lime-soap succeeds, and the agglomeration into small nodular masses. The admission of sulphurous acid is now stopped, but the injection of the steam is continued until the small masses become hard and homogeneous. The whole period occupies eight hours, but the admission of sulphurous acid is discontinued at the end of about three hours.

The water containing the glycerine is run off from below by a tube to a large underground cistern.

FIG. 235.



The sulphurous acid is generated by the apparatus shown in Fig. 235, sulphuric acid and pieces of wood being introduced by *f f* into retorts *e e*, heated by a single fire *b*, with ash-pit, &c. The sulphurous acid is conveyed to the boiler A by leaden pipes *g g*, where the saponification is effected under the joint influence of the acid and steam.

The lime-soap is then moistened with 12 cwt. of sulphuric acid at 53° R. (152° F.), diluted with 50 gals. water. The whole is thoroughly agitated, and the steam cautiously admitted, so as not to dilute the acid too much until the decomposition is general at all points. This occupies about three hours, and in two or three hours more the sulphate of lime has collected at the bottom, while the fatty acids are floating on the surface of the solution of the bisulphate of lime.

B, (Fig. 3,) represents the vat filled with the masses of the lime-soap; *h*, the pipe for conveying the liquid into the main drain *i*; *k*, main steam pipe; *l*, open steam pipe; *m*, wooden spout to carry the fatty acids in the vat, (Fig. 4).

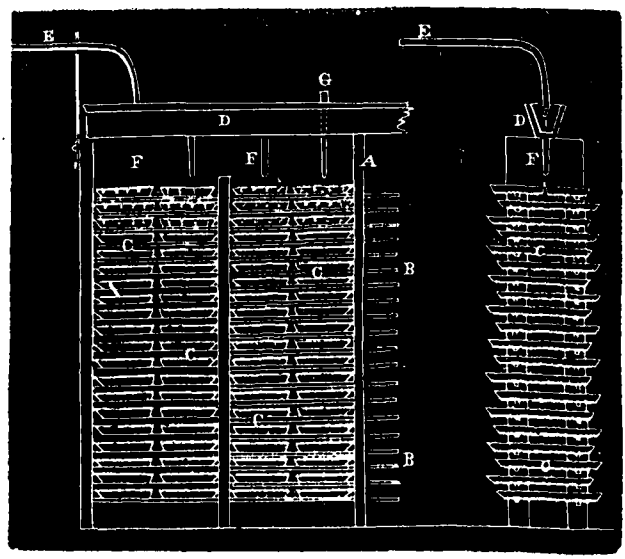
Some adhering portions of sulphate of lime are removed to a vat, *c*, (Fig. 4), lined with lead. *o*, pipe for free steam; *p*, another pipe for dry steam; *r*, layer

of acidified water; *s*, position of charred organic matter; *t*, layer of fatty acids; *u*, copper syphon, with a perforated copper disc to prevent the passage of charred matters; *x*, air-cock; and *y*, discharge-cock for fatty acids.

After settling during four hours, the fatty acids are forced through a fixed syphon into a vat D, (Fig. 7,) by means of a hydrobalistic pump, where they are washed with water, as in the preceding case. The machinery is supported by a metal frame-work *a'*, where the handle of the pump is marked *b'*; intermediate shaft *c'*; shears *e'*, with two pulleys *f f*, one fixed and another loose; fly-wheel *g'*, and *h* a lever for putting the whole in or out of gear. The details of the washing, steam pipes, &c., are the same as in the preceding vat (Fig. 4).

The fatty acids are washed a third time with water, and syphoned

FIG. 236. FIG. 237.

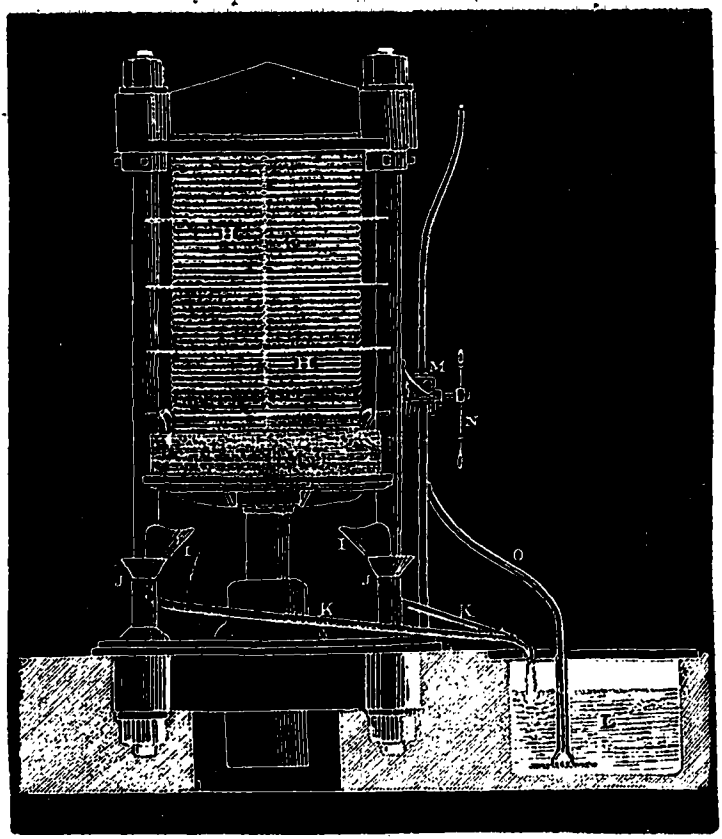


at last into the trough D, lined with lead, on the bottom of which are placed leaden gutters, pierced below by long pegs of wood. Figs. 236 and 237 represent a wooden frame-work A, bound by transverse bars of iron, B, which support the moulds C C at the same time. F F are leaden funnels, through which the fatty acids are run into the moulds. G is a wooden plug for stopping the funnels, F, when the moulds are full.

The cakes of fatty acids are enclosed in bags of flannel H, and

submitted to pressure in the cold in an hydraulic press F, Fig. 238. I, sheet-iron gutter for oleic acid, from which it flows into the

FIG. 238.



funnels J J, and thence by the pipe K into the reservoir L. M N O F, arrangement for conveying oleic acid to a washing cistern. This operation lasts three hours.

It is important to allow the fatty acids to cool slowly, which prevents too confused a crystallization, and much facilitates the expulsion of the oleic acid.

The cakes are now placed between sacks of horse-hair, and submitted to a second pressure at a high temperature. The whole is covered with an oil-skin, and the temperature raised to 70° C. (158°.5 F.), when the pressure is applied. The heat slowly falls to 45° C. (113° F.), and ultimately reaches 35° to 30° C. (95° to

86° F.) Figs. 239, 240, and 241 show the arrangement in all its details, which do not require further explanation. This operation

FIG. 241.

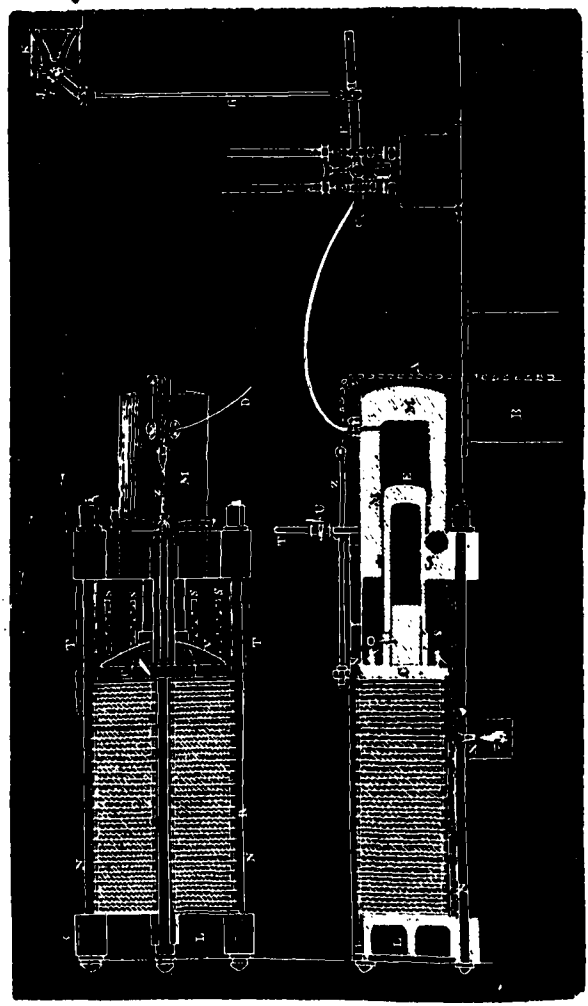


FIG. 239.

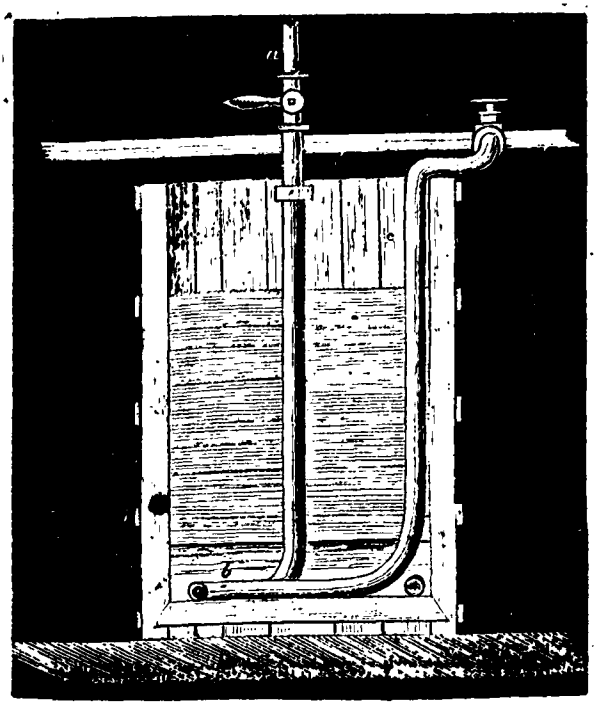
FIG. 240.

lasts about an hour, but the oleic acid obtained in this process contains large quantities of stearic and margaric acids, so that it must be returned to a special cistern, thence to the acidulated water and the subsequent washings from fresh quantities of the original fatty acids.

The cakes of stearic acid are sorted according to colour and

translucency, and about 20 cwt. are then introduced into a vat, H, Fig. 242, constructed of wood lined with sheet-iron. The materials are boiled by means of steam admitted through a leaden pipe *a*,

FIG. 242.



which is afterwards employed in heating a stove. Water acidulated with sulphuric acid is first employed, and afterwards pure water. When the materials are boiling, the white of 22 eggs is introduced, and the albumen is intimately mixed by the violent ebullition. As soon as the albumen is coagulated, the whole is allowed to cool, and the stearic acid is removed to another apartment, where it is kept in a state of agitation, to prevent the formation of crystals and allow the cooling to be as gradual as possible. The moulds for the candles are also heated to a temperature of 50° C. (122° F.), and are fixed on a carriage (Fig. 243) to the number of 117. The wicks are dipped for twenty-four hours in a weak solution of boracic acid, and rapidly dried, when they are introduced into the moulds. Fig. 243 shows the position which the moulds occupy before being trimmed with the wicks. The moulds are placed three in a row, *e e e*, Fig. 244: *g*

FIG. 243.

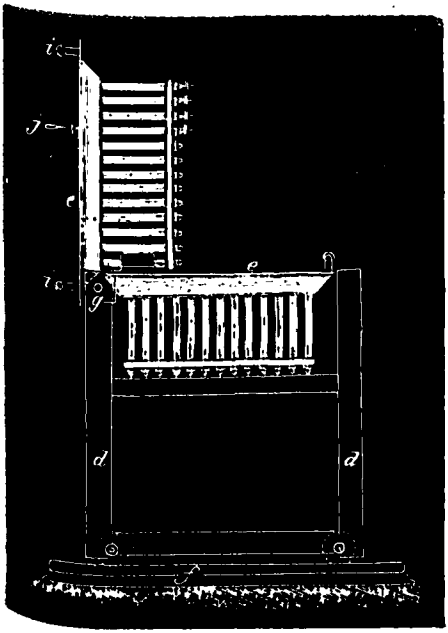
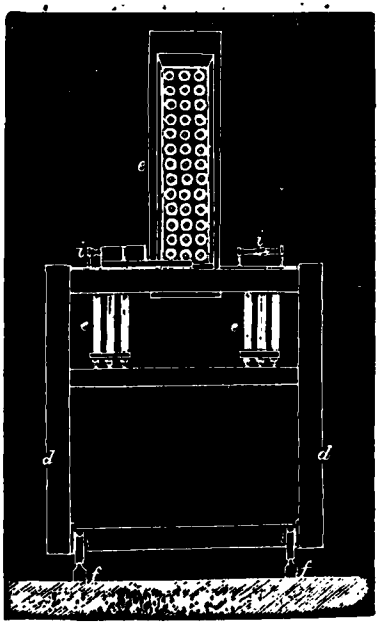


FIG. 244.

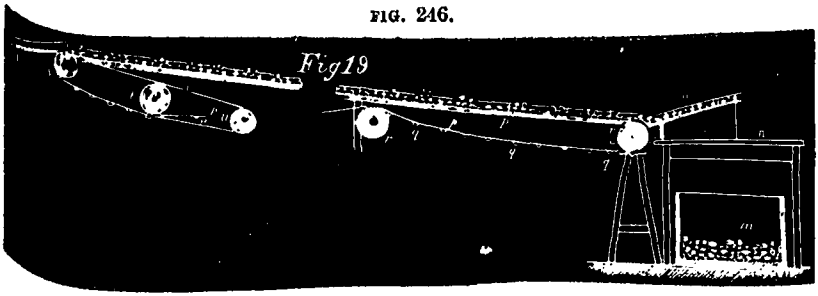


is the pivot round which the moulds are moved; *i i* handles for raising the frames; *j* hook for placing the wicks. Fig. 245 represents a frame filled with stearic acid, furnished with handles to facilitate the removal of the candles.

FIG. 245.

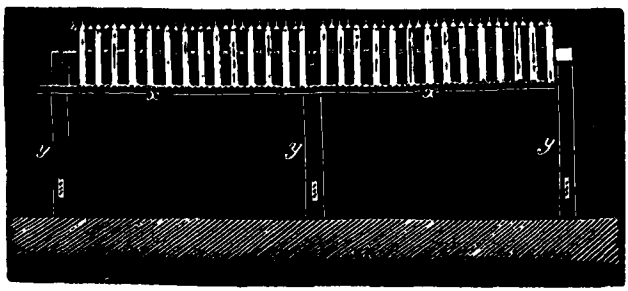
The candles are placed in a case, *m*, and afterwards on a table, *n*, whence they are thrown on an inclined plane and carried forward on an endless belt, as shown in Fig. 246, which represents the arrangement for raising the candles in a longitudinal and vertical section.

FIG. 246.



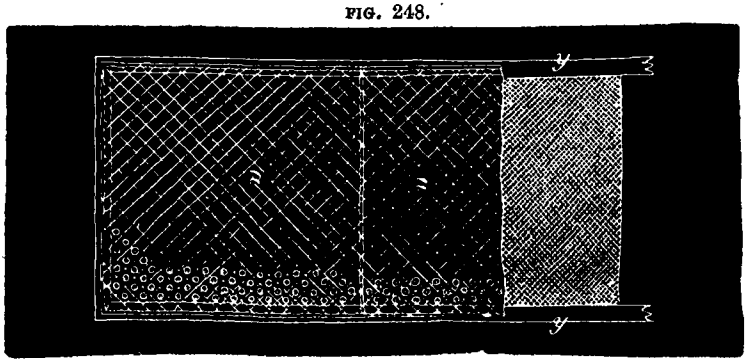
m is the bin or case to which the candles are carried previous to their being arranged on the table *n*. The hopper or incline on which they are afterwards laid is shown at *o*, from whence they pass to an endless belt of cloth (*p*) with semicircular hollow rods *q q*, which maintain them in their position; *r r*, wooden rollers for supporting the endless belt; *s t u*, system of rollers and pulleys connected by the leather straps *o*, which give motion to the endless belt; *f*, a wooden sloping bench, down which the candles slide into a receptacle prepared to receive them. The candles are then placed on a wire grating of lead in a wooden

FIG. 247.



frame, Figs. 247, 248, and exposed to the bleaching action of the air. Fig. 247, front view, and Fig. 248, plan of a frame

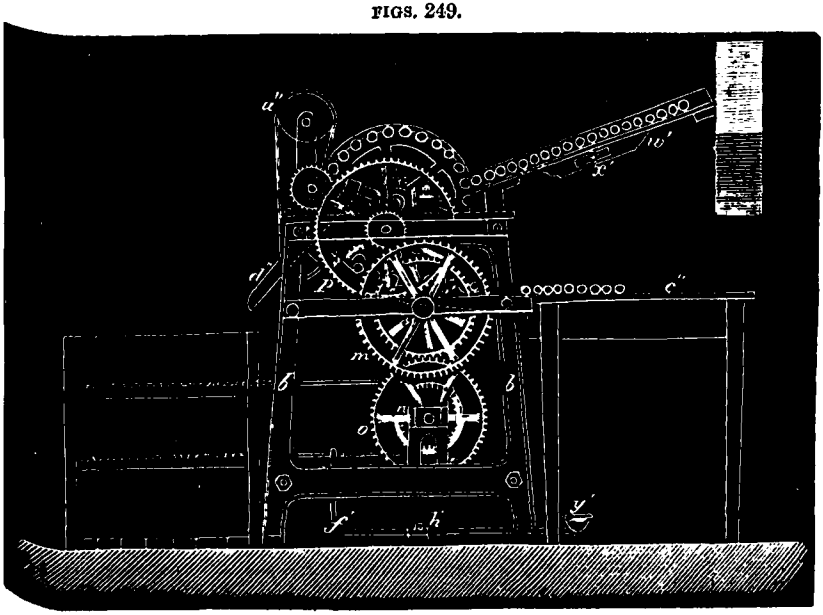
FIG. 248.



filled with candles. *y*, framework of wood; *z*, lower gauze of lead on which the candles rest; *a a*, upper gauze with meshes sufficiently large to admit the candles, which are thus kept in an upright position and fully exposed to the bleaching action of the air. They are then removed to another department, where the ends are cut square by means of a circular saw, as shown in the Figs.

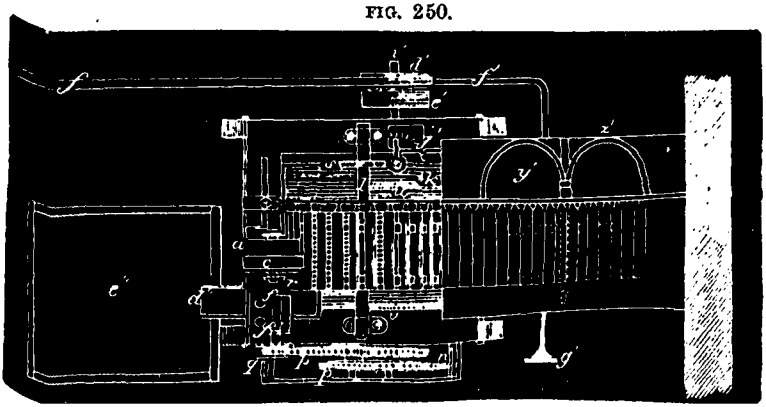
249 and 250. *b'*, iron framework; *c'*, leather belt which gives motion to the machine; *d'* moveable sheave; *e'* fixed sheave; *f*, forked lever, moving on the fixed point, *h'*, for putting the belt

FIGS. 249.



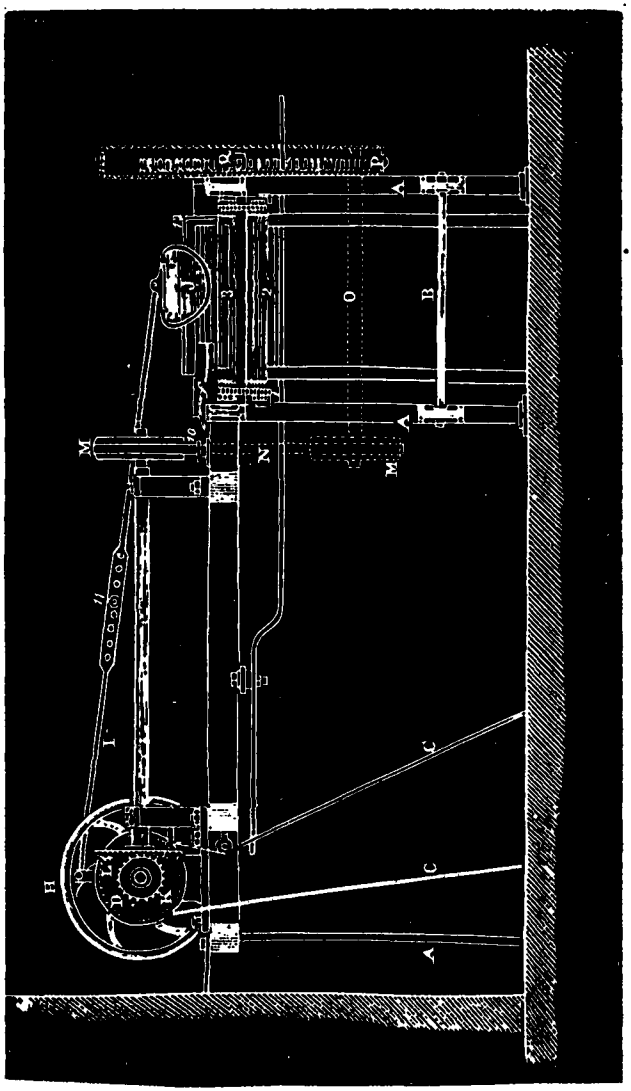
in or out of gear by means of the foot-board, *g*. *i'*, shaft of the multiplying system of toothed wheels, *j' k' l' m' n' o' p'*; which command the small wheel *q'*, which divides the saw *r'*; *s'*, a wheel at right angles mounted on a horizontal shaft *t'*, which receives two vertical and parallel wheels *u'* and *v'*. The space between the

FIG. 250.



teeth, which are cut in a semicircular form, catch the candles and draw them forward as they lie parallel with each other on the incline. *x*, screw for regulating the position of the movable and vertical board *y*, which determines the length of the candles, according as it approaches the point *z* or not. *a'' b''*, two wooden sheaves—connected by an endless belt crossed for the purpose of

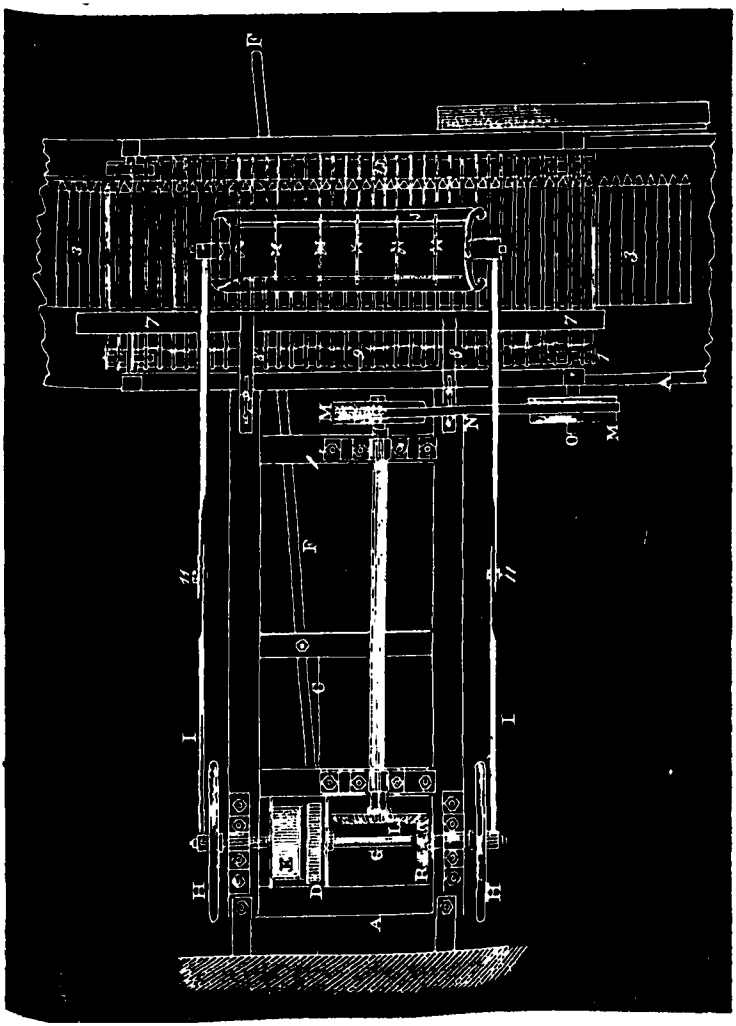
FIG. 251.



retaining and guiding the candles, which slide down a board slightly curved to the table *c''*. The hopper *d''*, lined with tin, receives the cuttings which fall into the box *e''*; *f''*, two iron shields for guiding the cuttings. The candles are afterwards plunged in a weak solution of carbonate of potash, cleaned and rubbed smooth with a linen cloth.

The next process is the polishing, which is a purely mechanical

FIG. 252.



operation, produced by friction between two surfaces of flannel, which is repeated fourteen times, after slight defects are removed by a workman with a piece of flannel.

Figs. 251 and 252 will explain the polishing process. A A, framework in the form of a kind of cross, and strengthened by the beam B; C, leather belt driving the fixed sheave D, or the loose one E; F, lever for putting in or out of gear; G, moving axle which carries the two fly-wheels H H, which also serve as handles. I I, two shafts attached to the wheels H H and the rubber J in the form of a half-cylinder covered with several folds of woollen cloth and flannel. K L, two toothed wheels working at right angles, driven by the belt C, and giving motion to the shafts I I, the rubber J, and the rubbing sheave M. N, belt which connects the sheaves M M'. The latter sheave is fixed on a horizontal shaft O, with a pinion wheel P at the end, working into a large toothed wheel Q. The horizontal shaft O also carries two small wheels with square teeth I I, which give motion to a kind of endless chain, 2, composed of rods of iron, and between which the candles, 3, are placed.

A small table covered with flannel is fixed under the endless chain, on which the candles roll as they are drawn forward from an incline where they are arranged parallel with each other. The candles are retained in their position under the rubber by means of a guide, 7, regulated by two elastic springs, 8 8, and after repeated rubbings are deposited on a table, 6, at the other end of the machine.

The acidulated water employed in the process, and which contains some sulphate of lime, is run through a funnel-shaped body, which retains the fatty matters mechanically mixed with it, while the purified acid liquid can be again employed. The insoluble sulphate of lime is repeatedly washed with water to collect every trace of fatty matter.

When any peroxide of iron is accidentally mixed with the stearic acid, it has been found that a small quantity of oxalic acid assists in purifying the whole.

Messrs. Moinier and Boutigny have since obtained a patent for employing coke, coal, stone, or other insoluble substance, over which the liquid fats to be distilled are allowed to trickle in a fine rain, while steam passes through the still in the opposite direction. By thus exposing a large surface to the action of steam the fats may be distilled at a lower temperature.

The following is the monthly expense of working at MM. Joillon, Moinier, and Co.'s manufactory:—

		Fr.	C.
1. Melting of the fat	10 workmen at 4¼ fr.	1275	0
	1 general foreman	200	0
2. Saponification	1 foreman at 4 fr.	120	0
Decomposition	4 men, night, at 3 fr.	360	0
Washing, &c.	4 men, day, at 3 fr.	360	0
3. Purifying of the acid sulphate of lime	1 chief at 3½ fr.	97	50
	3 men, each day and night, 2¾ fr.	495	0
4. Presses	2 chief at 4 fr.	240	0
	5 men, each day and night, 2 fr. 90 c.	870	0
5. Sorting of the fatty acids	6 men, for day and night, at 1 fr. 40 c.	252	0
6. Refining, clarifying, &c.	1 foreman at 4 fr.	120	0
	2 assistants at 2½ fr.	150	0
	20 workmen at 1 fr. 65 c.	990	0
	2 children at 90 c.	54	0
7. Washing, cutting, polishing, &c.	1 foreman, at 3 fr.	90	0
	60 women, boys, and girls, at 1¼ fr.	2250	0
8 Preparation &c. of the wicks	2 women, at 1 fr. 40 c.	84	0
9. Purification of the stearic acid in blocks	2 women at 1 fr. 40 c.	84	0
	4 women at 1 fr. 25 c.	150	0
10. Steam engine	2 men, night and day, at 3 fr. 65 c.	438	0
11. Forges, &c. &c.	6 mechanics at 4 fr. 20 c.	756	0
12. Joiner's shop	2 men at 4 fr.	240	0
	1 apprentice at 70 c.	21	0
13. Oleic acid warehouse	1 cooper, at 3 fr.	90	0
	2 labourers at 3 fr.	180	0
14. Candle warehouses	1 foreman	125	0
	1 sub-foreman	120	0
	2 children	80	0
15. Labourage	3 men at 2 fr. 40 c.	216	0
16. Superintendence	1 man at 2 fr. 50 c.	75	0
17. Carriage of goods	2 porters at 3 fr. 50 c.	210	0
18. Stable	1 cart-man at 3 fr.	90	0
	1 groom at 2 fr.	60	0
19. Clerk	at 3 fr.	90	0
		11032	50

Chevreul's researches not only led the way to the production of the fatty acids by the agency of bases, but also indicated the action of the strong acids upon the fats. It was, however, reserved for Frémy clearly to define the close analogy between the action of acids and alkalies upon this class of bodies. When tallow or any compound fat is treated with strong sulphuric acid, both the fatty acids and the glycerine combine with the sulphuric acid to form the conjugate acids—*sulphostearic, sulphopalmitic, sulpholeic,* and *sulphoglyceric acids.* On treating this mixture with water, the sulphoglyceric acid is resolved into glycerine and sulphuric acid, while stearic, palmitic, and oleic acids separate on the surface of

the water, in which the sulphuric acid previously combined with them dissolves.

In 1840 Gwynne obtained a patent for decomposing the fats in this manner, and subsequently distilling the acids in a vacuum pan similar to those employed in refining sugar. The process did not prove remunerative, in consequence of the expense attending the production of a vacuum.

Clark succeeded also in saponifying the fats in this manner with a very small quantity of vitriol, but the separation and purification of the products without distillation proved too expensive.

Dubrunfaut obtained a patent in 1841 for distilling oils and fats by passing steam through them at a high temperature, by which means the disagreeable odour was removed from them; but little application was made of this process to the solid fats.

In 1842 Jones and Wilson patented the combined application of oil of vitriol at a high temperature and distillation by steam to the purification of the fats. Subsequent additions to their original plans, involving the reduction of the amount of acid employed from 10 lbs. to about 6 lbs. for every 112 lbs. of fat, increasing the temperature of the fat before the steam was admitted, and employing steam heated after it leaves the boiler by passing through a serpentine tube in a furnace, both before the sulphuric saponification and for distillation, have at length brought this important branch of manufacture to its present state of perfection. By the aid of this invention the cheaper vegetable fats, palm and cocoa-nut oil, the refuse from the kitchen, the oily residues from woollen and other manufactures, and similar waste products, are converted into material for the most excellent candles.

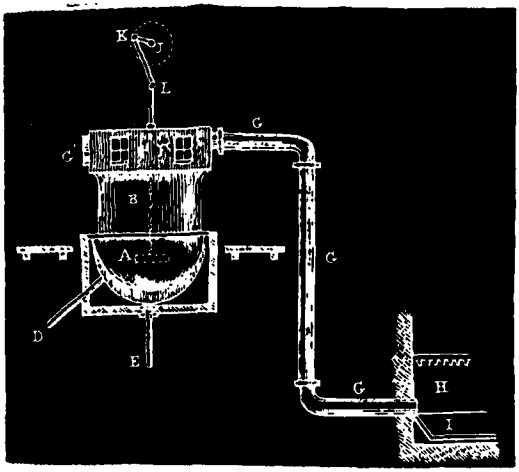
The distillation of fatty acids derived chiefly from palm oil, is now carried out in the following manner:—

After washing with weak sulphuric acid, about two tons of palm oil with 2½ cwt. of concentrated sulphuric acid are introduced into a boiler, Fig. 253, A, made of strong sheet copper or iron lined with lead, heated by steam inclosed in the casing C. The tube D carries off the steam, and E the condensed water. This is enlarged by a cylinder B, made of sheet lead, on which is fixed a chamber F, made of thinner sheet lead, with two side windows, a large man-hole door G, and a tube G′, which communicates with an ash-pit H, on the bottom of which an open iron cistern rests.

All sulphurous acid, fatty acids, acroleine, &c. are thus destroyed in being made to pass through the heated fuel.

An agitator, A L, similar to a churning-stick, and turned by a handle K J, keeps the mixture well agitated, and prevents the oil of vitriol from falling to the bottom.

FIG. 253.

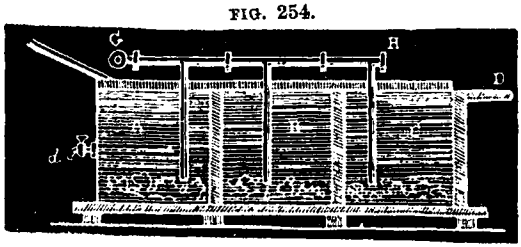


The temperature is kept up to 110° or 115° C. (in this country to 350° F. by hot steam), and the operation lasts from twelve to eighteen hours. A sample which crystallises readily when taken from the boiler, and has lost its violet hue, indicates the termination of the process.

After cooling for two or three hours the contents of the still are run into a cistern A, Fig. 254, two-thirds filled with water, while a current of steam is admitted by the main-pipe G H, through A.

The compound fatty acids are decomposed at a temperature of 100° with the assistance of water, and they are found floating on the surface. Fresh boiling-hot water is added to wash them, and the foreign matters dissolving pass under the partition into B, where the same operation is repeated, and so on to C. The water flows off at D into tanks constructed of masonry, for further use. The fatty acids in A are drawn off at *a'*, above the level of the water, and those in B and C are skimmed off, in order to be further washed.

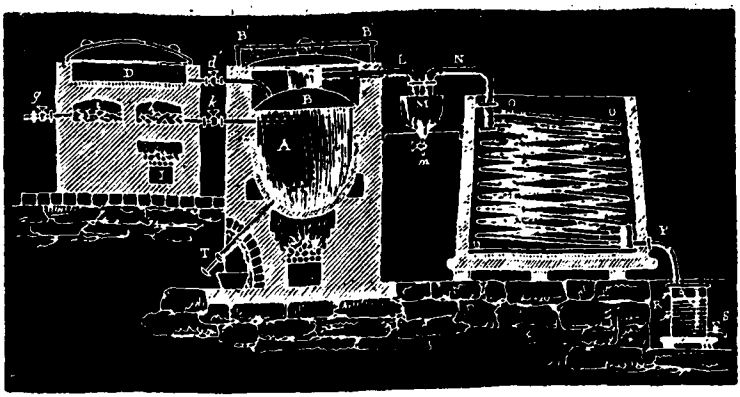
FIG. 254.



The fatty acids are then heated in a metal vessel D, Fig. 255, with a cover of tinned copper, forming a lute on the edge, in which the condensed water falls and runs off. The heat for drying the acids is the spent flame of a furnace J, which heats the spiral

metal pipes lying in the arched chambers *i* and *h*. These spiral pipes are intended for heating the steam to 300° before it enters

FIG. 255.



the boiler A, where it is spread by a rose. The cocks *g* and *k* are for the purpose of regulating the supply.

The boiler A is of copper, with a cover B surmounted by a man-hole door. The liquid fatty acids enter by a pipe through the cock *d'*, and the loss of heat by radiation is prevented by a sheet-iron cover B' B' filled with fuel.

When the temperature of the acids has reached 250° the hot steam is admitted by opening the cock *k*. The fatty acids pass over with the steam through L into an intermediate vessel M, and thence through N to a worm O O, where they are condensed and flow through a pipe P into a florentine receiver Q.

The lighter fatty acids are drawn off at R, while the aqueous portion, passing under the division, flows off at S.

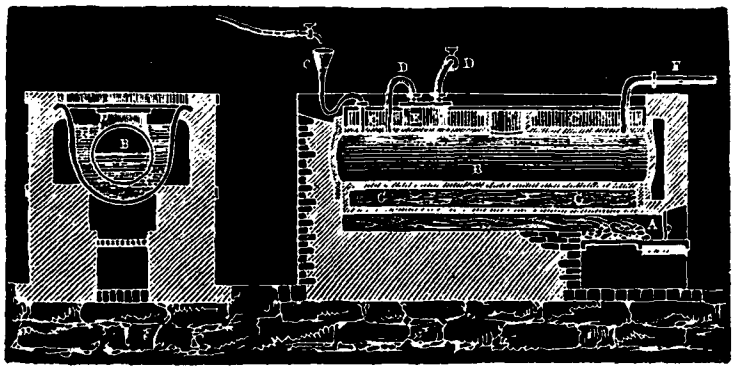
The little cock *m* of the intermediate vessel M is intended to draw off the matters carried over mechanically by the ebullition.

The brown liquid residue left in the boiler is drawn off by a pump T.

Another arrangement has been tried to render the distillation continuous. It consists of a common steam boiler B, Fig. 256, heated by an intermediate lead-bath G G. It is furnished with an ordinary man-hole door. The prepared fatty acids are admitted by a funnel *c*. The heated steam is admitted at D, passing through the intermediate vessel E, where the condensed water is converted into steam. The fatty acids and steam pass off to the condenser through F. It has been found, however, much

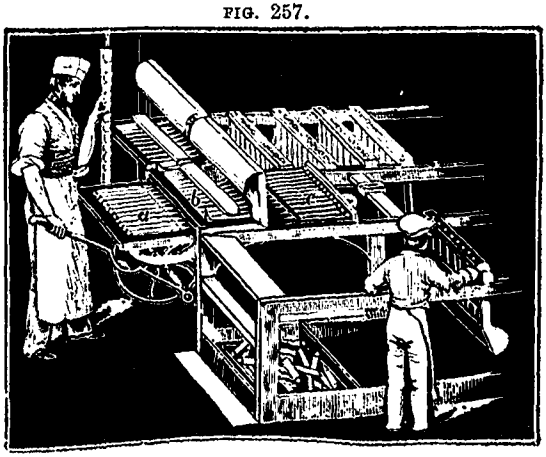
better to convey the steam down into the body of the liquid, to ensure a more perfect action.

FIG. 256.



Candle Machine.—The highest-priced candles are still made in the ordinary moulds, but a machine is used at Messrs. Price and Co.'s works for moulding ordinary stearic acid, cocoa-stearic, and composition candles, which, in discharging one set of candles from the moulds, rewicks the moulds for the next process of filling, and thus saves a very large amount of labour and time. The small conical tops of the moulds employed with this machine are movable, and can be pushed down into the cylindrical part of the mould, but on returning to the top are prevented by a rim from passing beyond the cylinder. The moulds are arranged side by side, eighteen in number, on a frame, and for each mould there is a reel capable of containing sixty yards of wick enclosed in a box attached to the frame. In order to understand the action of the machine, shown roughly in Fig. 257, the frame of moulds *b*, must be imagined filled with candles with the wicks pro-

FIG. 257.



truding at the top, and still in connection with the reels, brought into a horizontal position exactly in front of a set of plungers, which the workman draws forward by means of a lever. Each plunger is thus pressed against the conical cap of a mould, and in forcing it into the cylinder ejects the candle and carries a portion of wick into the mould to be coated by the next charge of melted fat. The candles are projected, as shown at *a*, and a piece of wood covered with flannel, moving on a hinge and cut out to fit the candles, is pressed upon them for the purpose of holding them firmly, while a circular knife travels between *a* and *b*, which cuts off the wicks of the finished candles, leaving a portion, intended for the following charge, protruding from the moulds. The prominent portions of the wicks are now firmly clasped by a number of forceps attached to a rod; the plungers are then drawn back, taking with them the conical caps of the moulds, and tightening the wicks; the whole frame, wick-box and all, is then inverted, the conical ends downwards, on to a pair of rails at the side, where a boy pushes it forward towards a hot closet, where it acquires the proper temperature before being filled. The fat is contained in a cistern above the rails, in which it is kept at the melting point by steam-pipes; and as each frame is brought under it after leaving the hot closet, the moulds are filled by as many cocks or outlets from the cistern. The frames travel to the end of the rails, which are of considerable extent, and when the fat has solidified the forceps and superfluous material are removed, and the frames transferred by a travelling truck to a parallel set of rails on the other side to be brought again opposite the plungers when the candles are expelled. Each machine has on an average 200 moulds, each mould contains 18 bobbins, and each bobbin, when first cottoned, 60 yards of plaited wick; so that when the seven machines in Messrs. Price's factory are at work at once, there would be a length of 800 miles of candles on hand. The only objection to the machine is the possibility of a careless workman with a crooked forceps allowing the wicks to move from the centre of the candles, which with refractory material are occasionally rather hollow at the bottom: the old-fashioned hand frames are therefore preferred for hard high-priced candles.

Six descriptions of stearic candles are made at the Vauxhall Works, differing in the material whence the mixture of fatty acids is derived. Belmont sperm is made from hot-pressed palm acid: Belmont wax is of the same material, but tinted with gamboge to give it the appearance of wax and suit the taste of some consumers.

Inferior candles are also sometimes coloured to hide their defective whiteness. The best composite candles are a mixture of Belmont sperm with cocoa-nut stearine. The composite Nos. 1, 2, and 3, are made of palm fat acids alone, differing only in their colour and melting points. The retail prices of these candles range from $6\frac{1}{2}d.$ to 1*s.* per lb. An attempt was made by the same firm to introduce transparent candles composed of an outer casing of wax and stearic acid, filled up with crystalline stearic acid radiating from a centre, but they did not meet with a favourable sale.

The No. 2 composition is employed in preparing the Albert night lights, which are short thick cylinders of fat, with a very thin wick, so proportioned to the diameter of the cylinder that it shall burn during 6, 8, 9, or 10 hours. These are made in a metal frame perforated with a number of cylindrical holes, to each of which there is a movable or false bottom with a thin wire projecting upwards in the centre. The cylindrical holes being filled with the melted fat, and this having cooled, the bottoms are forced up by a lever, and the cylinders of fat ejected all at once, each pierced with a central hole, into which the wick has to be inserted. The wicks, previously impregnated with wax, which renders them stiff, and having a small piece of tin as a support for the bottom, are very dexterously and quickly inserted by children, and the bottoms made fast by suddenly pressing the wick'd cylinders on a warmed porcelain cup, which melts the fat in contact with the piece of tin. It has also been proposed to make the cases of night lights of gelatine, or a mixture of gelatine and gum, which can be cast of any size or shape in a mould. These lights are burned in small glass cylinders, into which they fit. Child's night lights are made by pouring the melted material into cylindrical card-board boxes with a hole in the bottom, into which the waxed wick and metal support have previously been placed. Price's patent night lights are similarly prepared, but consist of cheaper material.

Spermaceti.—In some of the larger Cetacea, particularly in the white whale (*Physeter macrocephalus*) of the South Sea, there are peculiar cavities in the bones of the skull which are filled with a kind of blubber (a specifically light substance), apparently intended to throw the centre of gravity of the animal further back towards the middle of the body, and thus render it more capable of swimming. Immediately on leaving the skull of the slaughtered animal, this oily fluid begins to deposit small crystalline laminæ—*spermaceti*—in large quantities.

In order to obtain the solid sperm, the crude oil is placed during cold weather in a cistern, below which a number of bag-filters are arranged, the upper parts of the bags being connected by a pipe with the oil cistern: the pressure of the oil forces the fluid sperm oil through the filter, while the solid fat remains. This operation is called "bagging," and the produce has a dirty brown colour, and still contains much liquid oil. The bagged sperm is placed in cloths, and submitted to a heavy pressure, which removes the greater portion of the oil. The pressed sperm is then melted and allowed to crystallise slowly; the crystals are again placed in the press, which is now worked with a force of several hundred tons; the oil which comes from the press is of inferior quality, and is sold at a reduced price. The cakes are now again melted in a large iron vessel, and boiled for about two hours, with a strong solution of caustic potash or soda, which saponifies any oil that may still adhere to the crystals, and is thus removed in the form of soap, while the spermaceti itself is not affected by the alkali. The melted fat is allowed again to crystallise in tin moulds; the cakes are broken up to powder, placed in linen bags between horsehair mats and pressed again between previously heated iron plates in a horizontal press kept hot by steam. The hot-pressed sperm is lastly again boiled with a strong alkaline ley at a high temperature, by which it is rendered as clear and white as water. It is then solidified in blocks for stowage.

The crude oil yields of purified sperm, 2 to 3 lbs. per gallon, and of sperm oil, 6 to 7 lbs.

Spermaceti is worth about 1*s.* 4*d.* per lb., and sperm oil 9*s.* per gallon, wholesale (August, 1854).

Animal charcoal has been used in some instances to purify spermaceti, but the process involves troublesome filtration at a high temperature, and is never employed in this country. The name *spermaceti* is derived from an erroneous opinion that this substance is the spawn of the whale tribe (*sperma ceti*). Commercial spermaceti is very white, semi-translucent, like alabaster, and much resembles stearine and stearic acid; it feels soapy, is brittle, and has a lamellar crystalline texture. Its specific gravity is 0.943. Spermaceti may be granulated to a fine powder by stirring it constantly while cooling from the melted state.

Commercial spermaceti is, with the exclusion of a small quantity of sperm oil, a peculiar fat differing chemically from the other fats. It was formerly called *cetine*, and was supposed, like tallow,

to contain oleic and margaric acids, combined with a basic substance which, however, in spermaceti, was not the oxide of glyceryle, but the oxide of cetyle ($C_{32} H_{33} O$). Cetine was considered a combination of two equivalents of margarate of oxide of cetyle with one equivalent of oleate of oxide of cetyle.

The recent researches of Heintz upon the animal fats have shown that spermaceti is composed of several fatty acids in combination with the oxides of cetyle ($C_{32} H_{33} O$) and stetyle ($C_{36} H_{37} O$). The following are the compounds:—

Stearate of oxide of stetyle	$= C_{36} H_{35} O_3, C_{36} H_{37} O$
Palmitate of oxide of stetyle	$= C_{32} H_{31} O_3, C_{36} H_{37} O$
Myristate of oxide of stetyle	$= C_{28} H_{27} O_3, C_{36} H_{37} O$
Laurostearate of oxide of stetyle	$= C_{24} H_{23} O_3, C_{36} H_{37} O$
Stearate of oxide of cetyle	$= C_{36} H_{35} O_3, C_{32} H_{33} O$
Palmitate of oxide of cetyle	$= C_{32} H_{31} O_3, C_{32} H_{33} O$
Myristate of oxide of cetyle	$= C_{28} H_{27} O_3, C_{32} H_{33} O$
Laurostearate of oxide of cetyle	$= C_{24} H_{23} O_3, C_{32} H_{33} O$

When the acids are separated from these bases the latter combine with water to form substances analogous to the alcohols called stethal and ethal, and composed respectively of $C_{36} H_{37} O, HO$, and $C_{32} H_{33} O, HO$.

Spermaceti Candles are moulded in precisely the same manner as those composed of stearine or stearic acid.

Bees'-wax is the substance which constitutes the cells of the beehive, and, according to Messrs. Hunter and Huber, is secreted by an organ situated in the abdomen of the bee. It was long considered a vegetable product collected by the insects from the pollen of flowers, and applied mechanically by them to the construction of the hive. The farina is now believed to be the food for the larvæ of the insect, while the wax is produced from the honey, for which it ultimately serves as a receptacle. The wax oozes out through the sacks where it is secreted, and is worked by the insect with its mandibles and proboscis, first into the form of a riband, which, softened with a frothy kind of liquor, making it white and ductile, is ultimately formed into cells.

The *honeycomb* having been secured, the *virgin honey* is allowed to flow out, while the remainder is removed by pressure. By simply melting the pressed comb in boiling water, and allowing the wax to cool slowly, the *wax discs* met with in commerce are obtained, the lower brittle layer, containing the precipitated

impurities, farina, &c., having been removed. The crude wax from the comb is melted several times in this country, and passed through hair bags into cold water; it is lastly melted and poured into conical moulds, previously wetted to prevent sticking, the shape of which aids the separation of the heavier impurities. Mr. Bagster melts the crude wax at once in an earthen jar over water containing one ounce of nitric acid to every quart; boiling is continued until the comb is melted; the heavier impurities subside in the acid water, and a cake is obtained consisting of three layers, the upper of pure yellow wax, a second containing some wax and impurities, and a lower which is entirely composed of dross. The last is removed, and the second is melted again with fresh combs. The impurities that accumulate, or old wax combs, may be pressed down in a tub for five or six weeks, when fermentation destroys the greater portion of the impurities, and the wax may be rendered as above described. Crude or yellow wax is sometimes very pale, sometimes greyish, but generally of a very deep brownish-yellow colour; it has a sharp, dry, granular and splintery fracture, is not easily kneaded, and when fresh and pure has a very agreeable smell of honey. The high price of wax often leads to a great deal of adulteration. The flour of peas, beans, and starch, is very frequently mixed with it, and even brick-dust has been used.

All these impurities, which sometimes amount to sixty per cent, are easily detected by oil of turpentine, which leaves them undissolved. Resin is discovered by means of cold alcohol. The worst adulteration of all—namely, that with tallow—is also, unfortunately, the most difficult of detection. When the smell and taste are not convincing, the formation of sebacic acid as the product of dry distillation proves the presence of tallow. The smell of tallow is also perceptible on blowing out a wax candle adulterated with that substance. Stearic acid is now sometimes added to wax, which raises its melting point. It may also be detected by boiling the wax with lime water, which, if stearic acid be present, loses its alkalinity and becomes turbid from the formation of a lime soap. Overbeck recommends boiling the adulterated wax with a dilute solution of carbonate of soda; effervescence and a lather are produced if a fatty acid is present, and the solution acquires a mucilaginous or gelatinous appearance according to the amount of adulteration.

The foreign matters derived from the farina and the honey, and which give rise to the colour and to the granular fracture of the

wax, must always be removed when the wax is to be applied to the manufacture of candles, in which form alone it is used as a source of light. This is done by *bleaching*. The facility with which wax is bleached varies with the source of the wax, and is also different at different times; it should, therefore, be first tested in small quantities taken from various parts of the whole quantity to be bleached, that it may be sorted and treated accordingly.

According to Mr. Barclay, the wax imported from Hamburg, Odessa, Portugal, Mogadore, Zanzibar, the East and West Indies, North America, as well as native wax, is easily bleached; while the produce of Cuba, Dantzic, Königsberg, Gambia, and Gubon, can only be bleached with difficulty and seldom acquires a good colour.

Gambia supplies the largest quantity of wax to this market, but considerable supplies are also obtained from Mogadore (which is frequently adulterated with fat); the East Indies, particularly Ceylon and Singapore; and North America.

A dark mahogany-coloured wax is obtained in Brazil, upon which the ordinary bleaching agent, sun-light, has no effect. It is the produce of a black bee which hives underground.

The destruction of the foreign matters in wax is easily effected by the aid of bleaching agents. When wax is melted with dilute sulphuric acid, it becomes decidedly darker, but exceedingly clear and translucent, and if again melted with a dilute clear solution of bleaching powder, a slimy or soapy troubled mass is produced, thick, and out of which weak hydrochloric acid separates the wax as a colourless clear layer which comes to the surface and solidifies to a perfectly white disc. Wax so prepared, however, according to the experience of wax-chandlers, does not keep its colour; its whiteness is not permanent. They therefore expressly refuse using it, and will only take wax bleached by the sun in the ordinary manner. Chlorine is also inapplicable to bleaching wax, in consequence of the substitution which occurs; chlorine taking the place of part of the hydrogen in the wax, is evolved as hydrochloric acid when the wax is burnt. The ordinary plan of bleaching is as follows:—

Yellow wax is melted over water in a vessel with a cock for decantation, and constantly stirred with about one-fourth per cent of tartar, which acts like a weak acid and clears the wax. In this country the wax is melted by admitting steam through a coil of perforated pipes, one pint measure of sulphuric acid being added for

every ton of wax, and well agitated with it: the sulphuric acid is both cheaper and more effectual than the tartar in separating the impurities. After being left at rest for a few minutes, the wax is drawn off into a second vessel containing lukewarm water, in which it is kept at a temperature nearly approaching that at which it solidifies. In front of this vessel is a stone or wooden cylinder, the lower half of which is immersed in a cistern of cold water. The pipe for drawing off the wax terminates in a disc pierced with holes, delivering on to the cylinder, which turns upon its axis, and is thus kept constantly wet. The wax is allowed to flow out in thin streams, which, falling upon the wet cylinder, become flattened and sink into the water in the form of thin ribbons. The *ribboned* wax is then spread out uniformly upon linen stretched in frames, and exposed to the dew and the light of the sun, until no further alteration of colour is perceptible. The ribbons after some time become white on the surface, but are still yellow in the middle; they are again melted and exposed, and this operation is repeated until the wax is perfectly white throughout. The process requires from five to ten weeks in this climate, according to the state of the weather. Abroad it is less tedious, but still involves great loss of time, labour, and material, which renders it very expensive.

The observation of the wax-bleachers, that in rainy weather the wax gets a greyish tinge, which cannot afterwards be removed, is as remarkable as it is difficult to explain.

The following plan has been proposed to quicken the bleaching, which must, however, involve considerable expense:—To 1 lb. of melted wax 2 oz. of pulverised nitrate of soda are added, and then 1 oz. of sulphuric acid diluted with 9 oz. of water is gradually stirred in, the mixture being kept warm. When all the acid is added the vessel is filled up with boiling water; on cooling, a perfectly white cake of wax is obtained, which must be thoroughly washed with hot water to remove any acid or sulphate of soda.

Bleached bees'-wax is cast for commercial purposes in small round discs, a few inches in diameter, and two or three lines in thickness; it has a very slight tinge of yellow, is translucent, can be kneaded at 85° F., and melts at 150° F., but is brittle in the cold. Wax is insoluble in water, and varies in specific gravity from 0.960 to 0.966.

Wax was formerly considered to be a mixture of two substances,

cerine and *myricine*, in variable proportions, the former being soluble, the latter nearly insoluble in alcohol.

Mr. Brodie has shown that cerine, or that part of wax which is soluble in alcohol, is a free volatile hydrated acid, having the composition $C_{54} H_{54} O_4$, and to which he has given the name *cerotic acid*. This substance is contained in ordinary English wax in the proportion of about 22 per cent, and can be precipitated from an alcoholic solution by acetate of lead. In bees'-wax from Ceylon it was entirely absent. Its melting point, when pure, is 171° F. The portion insoluble in alcohol (*myricine*) is a substance analogous to the fats, containing palmitic acid in combination with the oxide of mellissyl, $C_{60} H_{61} O$, which on separating from the acid combines with water to form mellissic alcohol, or mellissine, $C_{60} H_{62} O_2$.

When submitted to dry distillation, wax yields a fatty acid, supposed to be margaric acid (palmitic acid?), and a crystalline substance analogous in composition and properties to paraffine. Both liquid and gaseous hydrocarbons are also produced, and carbonic, but no sebacic, acid.

There is a large production of wax in this country, and considerable quantities are imported from the western coast of Africa, Tripoli, Tunis, and the territories of the East India Company. The heavy duty of 10 per cent in the year 1840, has since been remitted.

Wax Candles.—Wax is not adapted for moulding, in consequence of the contraction which it undergoes on cooling, and the tenacity with which it adheres to the sides of the moulds. The mode of preparing wax candles is analogous to the process of dipping; instead, however, of dipping the wicks into the melted wax, they are *basted* with it.

The wicks having been previously warmed in an oven, are attached to a hoop of wood or metal, suspended over the melting vessel, in the same position which they eventually retain in the candle. Whilst the wick is kept constantly turned round its axis by the fingers, hot melted wax is poured slowly over it from a ladle, beginning about 1½ inches below the loop; by turning the hoop the next wick is put through the same operation, and so on. Before more wax is poured over the wicks their position on the hoop is reversed, and that no wax may attach itself to the free portion of the wick, that part is covered with a cap or tube of tin. Wax is now again poured upon the wicks, one after the other,

keeping them constantly turned round as before. When the candles have attained a proper thickness at the bottom, which is the thinnest part, the basting ceases, that the cylinders may be made uniform. This is done by rolling them upon a wet table with a rolling board whilst still warm; and to keep up the proper temperature, they are laid between hot flannel, after removal from the hoop. The candles are then hung up again in their first position, the cap or tube having been removed from the prominent part of the wick, and they are basted a third time, the eye of the workman being his only guide to determine the extent. When the candles have attained the proper size they are again rolled and cut to a certain length. On breaking a wax candle, the annular layers, like the year-rings in wood, can easily be counted, and their number indicates the number of *bastings*. Time may be spared by dexterous management and much practice, and the wicks, hanging in the first position, may be covered at once with the proper quantity of wax.

The large church candles are made by placing a wick upon a slab of wax, bending this together, and then rolling it.

The long, thin, coiled wax tapers are drawn in a peculiar manner. The wick, which must be very uniform, and wound round a drum, passes from the latter into the wax pan, at the bottom of which a guiding roller is fixed; and from thence through a draw-plate to a second drum. The draw-plate is quite similar to that used in wire-drawing; it is a metallic disc, with holes corresponding in size to the diameter of the taper; these are, therefore, round when the taper is to be cylindrical, and in the shape of a star when the taper is to be grooved. The wick passes through smaller and smaller holes successively, until it has attained the required thickness.

Chinese, Japan, or *insect wax.*—Prior to the thirteenth century bees'-wax was employed as a coating for candles in China; but about that period the white wax-insect was discovered, since which time bees'-wax has been superseded by the more costly but incomparably superior product of this little creature, respecting the nature and characters of which, however, authors are at variance. From Abbé Grossier's description, it was suspected to be a species of *Coccus,* which has since been confirmed by Mr. Quekett's microscopical examination of the dead insect, called by Mr. Westwood *Coccus sinensis.* Sir George Staunton described the insect as belonging to the *Cicada* family in entomology (*Flata*

limbata). Chinese writers speak of it as an apterous insect. From the Puntzau and the Kiang-fangpu—herbals of high authority in China —Dr. Macgowan has extracted the following information respecting the waxy substance, *pe-la*, either yielded by this animal or exuded by the plant in consequence of the insect-puncture, upon which point there still exists a diversity of opinion.

The insect is supposed to feed upon an evergreen shrub, the *Ligustrum lucidum*, found throughout Central China, from the Pacific to Thibet; but the insect chiefly abounds in the province of Sychuan, and Mr. Fortune doubts the correctness of its feeding either on *Ligustrum*, *Rhus*, or *Hibiscus*, all of which are said by Julien to afford food to the insect. Mr. Fortune brought a plant resembling a species of ash to this country, which was given him as the wax plant. The plant is alive in the Botanical Gardens of Kew, but not in a condition to admit of its species being determined. Much attention is paid to the cultivation of the *Ligustrum*, or supposed wax plant; according to Macgowan, extensive districts of country are covered with it, and it forms an important branch of agricultural industry. In the third or fourth year of the planting it is stocked with the insect by man. In a few days after being tied to the branches, the nests swell, and innumerable white insects, of the size of nits, emerge and spread themselves over the plant, but soon descend to the ground, where, if they find any grass, they take up their quarters. If they find no congenial resting-place below, they reascend, and fix themselves to the lower surface of the leaves, where they remain several days, when they repair to the branches, perforating the bark to feed on the fluid within. They soon attain a somewhat large size. Early in June they give to the trees the appearance of being covered with hoar frost, being, as the natives say, "changed into wax." Soon after, they are sprinkled with water (probably that they may be the more easily detached) and scraped off. If this gathering be deferred till August, they adhere too firmly to be easily removed. Those which are suffered to remain to stock the trees for the ensuing season, secrete a purplish envelope about the end of August, which at first is no larger than a grain of rice, but as incubation proceeds it expands and becomes as large as a fowl's egg (!) This takes place in spring, when the nests are transferred to other trees, one or more to each, according to their size and vigour, in the manner alluded to. On being scraped from the trees, the crude material is freed from impurities by spreading it on a strainer covering a cylindrical vessel, which is

placed in a cauldron of boiling water. The wax is received into the former vessel, and, on congealing, is ready for market. The specimens received in this country were about 13 inches in diameter by 3½ inches thick, perforated near the centre.*

This *pe-la*, or white wax, is perfectly white, translucent, shining, the fresh surface crystalline, like spermaceti, but much harder, and not unctuous to the touch. It is tasteless and inodorous, crumbles into a dry inadhesive powder between the teeth, with a fibrous texture resembling fibrous felspar. Mr. Quekett has shown that it consists of a series of short filaments or hollow cylinders, some of which are straight, but others curved about one four-thousandth of an inch in diameter. When melted, and afterwards cooled, it crystallises precisely like spermaceti. The white matter collected about the young of the cochineal insect was found to be very similar, if not identical, in structure with the insect wax. Insect wax melts at 180° F., is insoluble in water, dissolves in essential oil and naphtha, and is scarcely affected by boiling alcohol, the acids or alkalies.

Mr. Brodie has examined the composition of this substance, and found the purified wax to consist of:—

Carbon . . .	82.235
Hydrogen . .	13.575
Oxygen . . .	4.190
	100.000

corresponding with the formula $C_{108}H_{108}O_4$. It may be broken up by saponifying agents into a fatty acid, *cerotic acid*, $C_{54}H_{53}O_5 + HO$, and the oxide of an alcohol radical, *ceryle* or *cerotyle*, $C_{54}H_{55}O$. The substance, even in the commercial state, is nearly pure: Cerotate of oxide of ceryle ($C_{54}H_{56}O$, $C_{54}H_{53}O_3$).

According to Mr. D. Hanbury, to whose paper on this wax in the Pharmaceutical Journal we are much indebted, about three tons of this wax were imported into London in the years 1846-47, some of which realised 1*s.* 3*d.* per lb., a price which was probably not remunerative, as no further supply has been received.

In China, candles are made of the substance itself, but it is more commonly mixed with softer fats, and used for coating more easily fusible material, and so prevent guttering. It is often coloured red with alkanet root, and sometimes green with verdigris.

* Hooker's Botanical Journal.

A patent has been obtained by Samuel Childs for employing this wax as an ingredient with stearic acid, spermaceti, and bees'-wax, in composite candles. It has the same property as bees'-wax of *breaking the grain* of stearic acid. In China the wax is likewise employed as a medicine.

Chinese wax costs at Ningpo from twenty-two to twenty-five cents per pound, and the annual product of the small creature in China cannot be far from 400,000 lbs., worth more than 1,000,000 Spanish dollars.

According to Solly, vegetable wax can be bleached easily and economically with nitric acid. With this view, sulphuric acid diluted with half its weight of water is poured into the vessel with the melted wax, and from time to time, the hot mass being constantly stirred, crystals of Chili saltpetre (nitrate of soda) are thrown in; sulphate of soda is formed, and nitric acid being evolved in considerable quantity, penetrates the layers of wax, and destroys the foreign colouring matters by oxidation.

Resin.—This substance is obtained from the sap of the *Coniferæ*, or fir-tribe, particularly from the genus *Pinus*, in which it is partly held in solution by a volatile oil, and partly produced from the latter by oxidation on exposure to the air. North America and Canada are the chief sources of resin, where it is procured by making incisions in the trees in spring, when the sap is in motion, and collecting the resinous juice. A tree in good condition affords from 7 to 9 lbs. per annum: more might be obtained, but only with injury to the tree. A white matter, like cream, is first collected, very different from ordinary turpentine, which is employed in making flambeaux instead of white wax. The juice that afterwards exudes is strained through a basket, in which the thicker portions remain, or is placed in leaky barrels exposed to the sun, or in a warm place, that the liquid may run off. The portion that passes through is collected in earthen pots, and sold as common turpentine; the thicker part is distilled with water as long as any oil passes over, leaving a yellow or dark-coloured residue. The product is *oil of turpentine* or *turps*, the residue *resin* or *colophony*.

M. Chevallier employs steam introduced into bags containing the crude turpentine, by which means a much purer product is said to be obtained, and in much larger quantity.

If oil of turpentine ($C_{20}H_{16}$) be constituted like the hydrogen acids, or be a combination of a carbo-hydrogen with hydrogen ($C_{20}H_{15}+H$), which is highly probable, then the production of

the resin is explained by the substitution of oxygen for hydrogen in the oil, the liberated hydrogen being also oxidised or converted into water. The resin of turpentine is a mixture of two isomeric substances, which are allied to the acids; they are sylvic acid ($C_{20} H_{15} O_2$), and pinic acid ($C_{20} H_{15} O_2$).

Different proportions of oil and resin, and other physical properties, serve to distinguish the commercial varieties of turpentine from each other. *Common turpentine* is obtained from *Pinus sylvestris* and *abies* (sometimes called rough turpentine, to distinguish it from oil of turpentine, which in the arts is called simply *turpentine*): it contains from 5 to 25 per cent of oil, is not very clear, of a whitish-yellow colour, and soon becomes hard. *Venice turpentine*, the produce of *Pinus larix*, is beautifully clear and colourless, containing 18 to 25 per cent of oil, but often adulterated; the thinner Strasburg turpentine, derived from *Pinus picea*, contains 33 per cent of oil. The Carpathian and Hungarian varieties are obtained from *Pinus cembra* and *mugo*. Canada balsam, from *Pinus canadensis* and *balsamea*, is the purest of all the varieties; in the fresh state it has the consistence of honey, an agreeable odour and bitter taste, soon becoming hard by exposure.

The *Pistacia terebinthus*, a native of the south of Europe and Barbary, affords a highly aromatic turpentine, called *China turpentine*.

Frankincense is obtained from *Abies communis*.

When common turpentine dries up, or hardens into resin upon the trees, it is called *pine resin*, or white resin. It consists of a hard crust enclosing a soft interior, which admits of being kneaded, and yields about 10 per cent of oil of turpentine. The quantity of common turpentine imported into the United Kingdom in 1851 was 431,950 cwts.

The resin has a yellow or brown colour, according to the extent to which distillation has been carried; it is brittle, and often presents a conchoidal fracture. At a temperature of about 69° C. (156° F.) it becomes soft and can be kneaded; at 135° C. (275° F.) it is completely liquid, and when distilled in close vessels affords much carburetted hydrogen gas, a thick combustible oil (resin oil), and an acid water, leaving about 0.75 per cent of carbon as residue. Its sp. gr. is 1.07 to 1.08.

Colophony is essentially a mixture of pinic acid with a small proportion of sylvic acid, and owes its dark colour to a portion of the former becoming converted by heat into colophonic acid. By

fusing colophony with a variable quantity of pitch, the substance known as *cobbler's-wax* is obtained.

Flockton has introduced a method of cooling the resin as it flows from the still, by allowing it to fall into porous earthen jars, previously saturated with water, and round which a stream of water is conducted during the hardening of the contents.

A very light yellow-coloured resin is obtained by boiling the ordinary resin briskly for a few minutes after the oil of turpentine has ceased to come over, and allowing the boiling liquid to flow from a shoot on to the surface of cold water, so as to form a thin stratum, which sinks as it cools, a constant flow of cold water being kept up until the resin is cold. About 5 or 6 per cent of water remains mechanically mixed with the resin thus prepared, which either renders it opaque, and of a light yellow colour, or else beautifully transparent, according to the quality used.

Oil of Turpentine. Camphine.—Rectified oil of turpentine is obtained by redistillation of the crude oil with potash, but this must be again distilled with water, and lastly with chloride of calcium, to obtain it perfectly pure. The oil then forms a perfectly limpid colourless liquid, of a peculiar odour and burning taste. Its sp. gr. is 0.865 to 0.870 at 60° F.: it boils at 314° F. It is almost insoluble in water, and not very soluble in alcohol, but readily mixes with fixed oils. It is very inflammable, and burns with a white flame, evolving much smoke when an insufficient supply of air is furnished to the flame. It consequently requires a particular arrangement of the wick and burner in order to be consumed in lamps (*v.* Camphine Lamps). The elementary composition of this oil, in its purest form, is identical with that of several others differing very much from it in physical properties. Amongst these are the oils of lemon, orange-peel, bergamot, pepper, cubebs, juniper, capivi, elemi, and laurel, all of which may be represented by the crude formula $C_5 H_4$. For oil of turpentine this formula is quadrupled, in consequence of the crystalline compounds which it forms with water, and which have the composition represented by

$$C_{20} H_{16} + 6\,HO.$$
$$C_{20} H_{16} + 4\,HO.$$
$$C_{20} H_{16} + 2\,HO.$$

Hydrochloric acid combines also with oil of turpentine, forming crystals of artificial camphor,

$$C_{20} H_{16}, HCl.$$

Sulphuric acid blackens oil of turpentine; concentrated nitric acid

and chlorine oxidise it so rapidly that the mixture spontaneously takes fire.

The distillation of crude turpentine was carried on to some extent in this country a few years ago, but has been stopped in a great measure by the Americans taking the process into their own hands. They now export spirit or oil of turpentine, and resin or colophony.

Resin was also employed in the manufacture of gas, and an apparatus for its distillation will be described below. The process does not appear to have been successful in an economical point of view, resin-gas not being able to compete with coal-gas in price, although greatly superior in purity and illuminating power. Mixed with hydrogen-gas as a diluent, it has again been made the subject of a patent by White, under the name of hydrocarbon or water-gas, of which an account will also be given when describing Illuminating Gas.

Resin is largely employed in the manufacture of yellow soap, but a considerable quantity is also distilled in close iron vessels, similar to tar or pitch-stills, for the sake of the fixed oil (resin-oil) which it yields. The distillation is not carried to the full extent in consequence of the difficulty of removing the hard solid carbonaceous residue which in that case attaches itself to the sides of the still, but when a large proportion of volatile and fixed oil has been obtained, and the residue is still liquid, it is drawn off, and solidifies to a hard cake of resin-pitch. According to Dumas, 1 ton of resin affords about 16.5 gallons of essential oil (similar to oil of turpentine, but less volatile, and having a much stronger smell), 150 gallons of resin-oil, and about 100 lbs. of resin-pitch. The pitch has still great resemblance to resin, but is nearly black in colour. It is employed for the same purposes as resin wherever the dark colour is not an objection.

An English manufacturer has favoured us with the following quantities as the result of his experience in the distillation of resin :—

194 cwt. of resin yield :

	Cwt.
Resin spirit	6
Resin oil	109
Pitch	32
	147
Acid	8
Waste in gas evolved during process	39
	194

The volatile oil is of little value, although it may replace oil of turpentine in certain of its applications.

The fixed oil is principally employed mixed with lime as a lubricating agent for coarse purposes, such as greasing cart and carriage wheels, and rough machinery. Resin is sometimes distilled with 5 to 10 per cent of lime, but is even then acid; and it is recommended to mix it for lubricating with from 2 to 5 per cent of lime, which gives it the consistence of butter.

Heated steam, in conjunction with the direct action of flame upon the still, has also been applied by Furck to the distillation of resin. An iron retort with a copper worm is employed, with a man-hole door for introducing the resin and removing the residues. Two pipes enter the still; the one passing to the bottom, and terminating in a perforated ring, blows steam into the melted resin; the other, in the form of a coil, in the upper part of the still, is supplied with steam to keep up the requisite temperature. The still being about two-thirds filled with resin, the direct fire is applied, and some steam introduced into the body of the still before connection is made with the worm. Water and acid now pass off at a temperature between 300° and 325° F., and the resin froths up considerably.

When the acid has been driven off, the condenser is attached, and steam blown into the melted resin, which first carries over with it the volatile oil or naphtha, amounting to about 15 per cent of the bulk of the resin employed. The temperature is then gradually raised to 500° F., and kept at about 550° F., with the constant admission of steam, until about 25 per cent of the resin has passed into the receiver in the form of oil; the temperature is then again raised to 600° F., and another 25 per cent of oil is obtained; and on increasing the temperature to 650°, a final product, amounting to 12½ per cent, is collected, which closes the operation. The residue in the still is liquid, and is drawn off by a discharge-cock. Steam is projected from the upper steam-pipe into the vapours of the oils during distillation, which is said to exert a further purifying action upon them.

By redistilling the oil obtained at 650°, with the introduction of steam to the vapours, and afterwards heating the product to 225° F. by steam, an oil is obtained suited for painters' use, and which is to be boiled like linseed oil.

The same oil, distilled at 650°, is adapted to the use of curriers and tanners, by redistillation with 5 per cent of slaked lime, at a temperature of 600° F., steam being introduced into it by the

lower pipe when the temperature has reached 300° F., and by the upper pipe to the vapours when the temperature indicated is 600° F. The product is redistilled with 5 per cent of caustic lime not slaked, and treated in an open vessel as above, when it becomes perfectly clear and free from acid. Oil for lubricating purposes is obtained from that portion which was collected at a temperature of 550° F. in the first distillation, 5 per cent of its weight of slaked lime being added to it, and redistillation and purification carried out as in preparing the oil for tanners' use.

The following is the mode of preparing grease for machinery in France:—The resin oil is boiled for two hours, and to every 97 parts of oil 1 part of zinc or lime is added, with a view of removing acid and water. A part of this oil is made into a lime paste by moderately heating 114 parts, and gradually adding 79 parts of slaked lime, under constant agitation for about twelve hours, when the mixture has become liquid and of a chocolate colour. The mixture is phosphorescent in the dark. One part of this mixture, while still warm, is added to 10 parts of the oil, with violent agitation, and the whole thrown into casks, where it solidifies before it is cold. The action of the lime in this preparation, and the cause of solidification, are still very obscure.

Resin oil is sometimes used to replace linseed oil in the preparation of printers' ink.

Mr. Calvert proposes to purify resin oil, and deprive it of smell, by heating the oil to 300° F. with sulphuric acid sp. gr. 1.345, in the proportion of 100 gallons of oil to 35 lbs. of vitriol. The product is separated from the charred portions and distilled with a little lime, to remove any traces of acid.

Naphtha.—The liquid hydrocarbons which are found in various localities, and derive their origin from the slow decomposition in the carboniferous strata, are sometimes employed for street-lighting in lamps. Thus in Genoa the streets are lighted with the naphtha from a neighbouring spring at Amiano. The oils derived from the dry distillation of cannel coal, bituminous shale, and from the refuse tar of gas-works, are also applicable to the same purpose. The mode of obtaining several of these has already been described in connection with the production of paraffine. As secondary products from the coal-gas manufacture, we shall have to refer again more particularly to coal-tar naphtha.

Coal.—This substance is the chief source of illuminating gas, and in addition to the information already contained in the fore-

going sheets of this volume, further particulars respecting its application to that purpose will be found under Gas.

Historical Notes on Candle Illumination.—Candles and lamps have been employed as means of illumination from the earliest ages. Mention is made of both in the Bible, where, indeed, it is difficult to know what was distinctly understood by the terms; lamps burning olive oil being ordered to be placed upon *candle*-sticks (Lev. xxiv.) Pliny, speaking of rushes and of flax, describes parts of them as suitable for lamps and candle-wicks, and although treating elaborately of the method of bleaching wax, nowhere mentions the material of which candles were made. There is no doubt, however, that both wax and tallow were used by the ancients in making candles, the wicks being composed of rope and the leaves of the papyrus. Apuleius distinguishes the two kinds as *cerei* and *sebacei*.

Torches appear to have been used at an equally early date.

Fosbrooke mentions that in the middle ages wax candles of various sizes were made in moulds, the wicks being formed of twisted tow; and King Alfred had wax candles constructed by his chaplains in such a manner that they marked the hours of the day, six candles lighted in succession burning exactly twenty-four hours.

Several records refer to the trade of wax-chandler as early as the 16th century; and in White's "Natural History of Selborne," 1775, the method of covering rushes with tallow, so as to form rushlights, is minutely described.

The first application of pressed tallow or stearine to the manufacture of candles appears to have been the invention of William Bolts, who obtained a patent for the process in 1799, as also for a particular method of burning candles by pressing them up to a wick by means of a spring, in a manner very similar to that now carried out more perfectly in Palmer's candle-lamps.

Theory of Candle Illumination.—Of the substances employed as sources of light, those which leave a solid residue on distillation can only be applied to the manufacture of gas, which, in being consumed at a distance from the place of its manufacture, admits of a distinction being drawn between gas illumination and the other sources of artificial light.

In the solid and liquid fats which leave no residue on distillation, the heat produced by the combustion of the gases they evolve in

giving light is employed to keep up the process of distillation. Thus, in a lighted candle, Fig. 257, the fat below the flame is melted into the form of a hollow cup, containing liquid fat, by the heat radiated downwards from the flame. This reservoir of liquid fat is the source *whence* the wick derives its supply, which is *regularly* renewed as long as the combustion of the candle goes on.

FIG. 257.

The power employed for raising the fluid fat to the sphere of combustion is *capillary attraction*, the interstices between the fibres of the wick forming a number of capillary cylindrical spaces. The substance of the wick must admit of being moistened by the liquid to be raised, and this is eminently the case with cotton and liquid fat; it must also be wholly consumed at the temperature of the flame. The flame is always produced at that part of the free wick which is in the middle between its point of most active capillary action, and the point where the flow of melted fat is excessive; it is, therefore, always at the same distance from the bottom of the cup *a*. In proportion as the candle diminishes, the flame is lowered and leaves the wick behind, which at last extends the whole length of the flame, or beyond it, and interferes materially with the evolution of the light. The wick, therefore, in a self-regulating candle, must be consumed as the candle diminishes in length. This circumstance has already been adverted to in describing the mode of preparing tallow and stearic acid candles.

In common mould candles, in which the wick is not plaited, and remains perpendicular in the flame, no air obtains access to it, and an accumulation of carbon or snuff is the consequence, which must be mechanically removed from time to time.

Tallow melts at from 20° to 30° C. (68° to 86° F.), and wicks which curl to the one side cause it to gutter, unless protected, as in Palmer's lamps, by a nozzle of metal. Tallow candles, indeed, generally gutter, in consequence of a disproportion in the size of the wick, or from the draughts of air which are unavoidable in an inhabited room. Wax, stearic acid, and spermaceti, all melt at a much higher temperature than tallow, and it is consequently far easier with these to establish a proper relation between the mass of fat, or the diameter of the candle, and the size of the wick.

Practice has long since established a certain relation between the size of the wick and the diameter of the candle, which varies, of course, with the material of which the candle is composed. In a well-constructed candle, there is always a reservoir enclosing liquid fat, formed by the unmelted fat at the circumference, the sides of which reservoir, as the flame descends, are themselves melted in their turn. If the wick be too large, guttering and smoke are the consequences, as in tapers, where no reservoir is formed; if the wick be too small, a thin solid ridge of fat projects, which not only throws a shadow, but is liable to fall into the melted fat, and thus also cause an overflow. Both extremes are therefore to be avoided to prevent guttering.

In night lights made of stearine or wax, where intensity of light is not required, a very thin wick is used, with a disproportionate thickness of fat, so that a very deep and full reservoir is formed, containing an excess of melted fat, which is prevented from flowing over by the paper envelope, or the small glass vessel used for sustaining the fat during combustion.

The supply of fuel to the flame of a candle is thus provided by the capillary action of the wick on the melted fat in the reservoir, but the fat thus brought up to the region of combustion is not all at once consumed and converted into invisible gaseous products. It first undergoes the process of dry distillation, being protected from the direct contact of air by the flame which surrounds it. If the flame of a candle be minutely examined, it will be found to consist of a dark central cone *f* (Fig. 257), in contact with the wick, filled with the carbohydrogens resulting from the action of the heat upon the fat. If one end of a thin glass tube, open at both ends, be introduced into this part of the flame, and slightly inclined towards the one side, these gases will enter the tube, and may be inflamed as they pass out at the other end.

A white zone of flame *e* surrounds this dark region, whence all the light of the candle is derived. The carbohydrogens produced in *f* here come into contact with the upward current of air caused by the heat of the flame. The hydrogen in these compounds first combines with the oxygen of the air, producing a very intense heat, while the carbon, for the simultaneous combustion of which there is an insufficient supply of air, becomes incandescent, and thus produces light. That carbon in the solid form actually exists in this part of the flame may be proved by introducing any cold body into it, when it will be blackened by the deposition of soot.

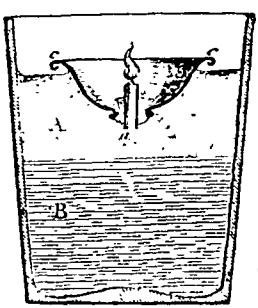
The luminous portion of the flame, lastly, is surrounded by a scarcely visible halo, where, if the size of the wick be duly proportioned to the diameter of the candle, the whole of the carbon is converted into carbonic acid, no portion escaping combustion in the form of soot.

LAMPS.

The fats which are liquid at ordinary temperatures require a vessel for support, into which a wick, or some mechanical contrivance, is introduced, which will raise the proper amount of oil to the region of combustion. The upper part of a candle, or the reservoir of melted fat from which the wick is supplied, might be called a tallow lamp, for in no essential point does it differ from a lamp except in the material of which it is composed.

Night lamp without wick.—The simplest form of lamp—which, however, is only adapted for a night light—is shown in Fig. 258.

FIG. 258.



Some water B being placed in a tumbler, or any other glass vessel, a layer of oil A is poured upon it, and a small floating vessel of glass or metal, with a tube of very small bore fixed in the bottom, so as to project upwards into the interior, is placed upon the surface of the oil. The height of the small tube in the interior of the floating vessel is so regulated with reference to the entire weight of the vessel, that the oil entering from below would flow into the vessel if not ignited; but the heat of the flame opposing the capillary action to a certain extent, allows the ascent of just sufficient oil to maintain combustion. Very little light is evolved by this simple contrivance, particularly if the floating vessel is composed of metal, when the ceiling only of the apartment will be illuminated. The size of the tube for supplying the oil cannot be increased beyond a certain very narrow limit, or the oil refuses to burn. The imperfect light and low position of the flame are overcome in a great measure by the use of a wick, but not without increasing the difficulty of producing a uniform flame.

Antique lamp.—The antique lamp, Fig. 259, with all its artistic perfection of form, which so often excites the admiration of connoisseurs, is practically a very imperfect arrangement for giving light. It consists of an open or closed oil vessel, containing an

FIG. 259.

unspun round wick, which is held by a nozzle, and by means of which a portion of oil is drawn by capillary attraction above the level of the great body in the lamp. It is obvious that in this lamp the level of the oil must sink as the consumption goes on, and that the wick must progressively raise the oil to a greater height, which ultimately becomes disproportioned to its capillary force; the flame then gradually diminishes, and is at last extinguished. A thick wick is also required, in order to afford a tolerable light, and then more oil is raised than can be fully consumed, and smoke is the result. The shadow of the oil vessel is also a very serious objection, and in order to obviate this to a certain extent the flame may be brought forward away from the vessel.

Kitchen lamp.—The common kitchen lamp, shown in Figs. 260 and 261, has this single advantage over the antique lamp,—

FIG. 260.

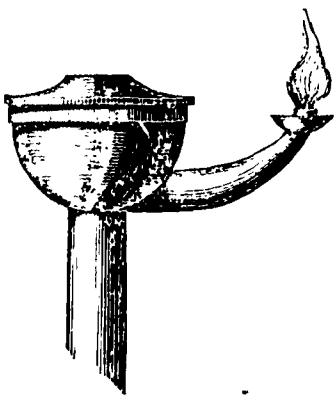
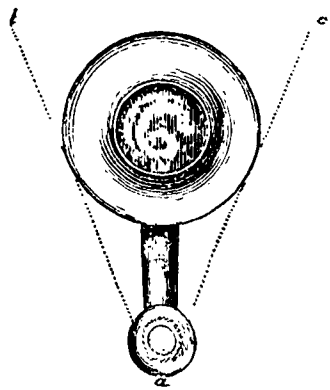


FIG. 261.



the burner being placed at a distance from the oil vessel, the light is not so much obstructed, or the angle *b a c* (Fig. 261) is more acute.

Modern invention applied to the improvement of lamps in connection with the different materials successively introduced as fuel for the flame, has been directed principally to the following essential points:—

a) The selection of such a form of wick that the quantity of decomposed oil, and the simultaneous supply of air, are so regulated that the hydrogen and carbon are *consecutively* consumed, and no *smoke* produced.

b) The preservation of a uniform distance between the flame and the surface of the oil during the whole period of combustion, so that the same quantity of oil may be drawn up at last as at first.

c) To place the reservoir of oil in such a position that the shadow which it throws shall occasion little or no inconvenience. The use to which the lamp is applied must always more or less regulate its form, and in some cases a shadow is not of much consequence. Thus the shadow thrown by a wall lamp is unimportant, as the lamp itself covers the shadow, and the same remark applies to the study lamp when used by only one person.

d) To throw the light radiated from the flame, by means of collectors and reflectors, from those parts where it is of little service, in the direction where it is most required.

The first objects have been met in two ways, either by regulating the access of air, or the supply of oil, and often by both at the same time. They have reference to that part of the lamp called the burner.

It would be an almost interminable labour to describe all the different forms of lamps which have been invented during the last half-century, the greater number of which present no new feature of importance. In the following observations we shall only direct attention to those forms which present important differences, and which from their novelty have formed epochs in the history of the subject.

Worms'-lamp.—In the countries bordering on the Rhine, the Worms'-lamp, shown at Figs. 262 and 263, is well known, and remarkable for the shape of the wick *t*. The fibres of the wick, instead of being collected into a circular form, are placed in small bundles side by side, forming together a flat ribbon. The effect of this is obvious. The edges of the flame are at no point so distant, that a nucleus can form in the centre, which, from want of air, will burn incompletely, and smoke. The flat socket *c* supports the wick; it is soldered in the diameter of the wide ring *d*, which, with its recurved edge, rests upon that of the glass globe *a a*. In addition to its flat form, the wick is also movable, which is likewise the case in all the following kinds of lamps. The teeth of a wheel *e* and *e'*, more distinctly seen in Fig. 263, are somewhat advanced into the space occupied by the wick, a cut being made in the socket, so that they press the wick in some measure

against the posterior side. According as the screws are turned, the wick is either raised or lowered, and a larger or smaller portion of

FIG. 262.

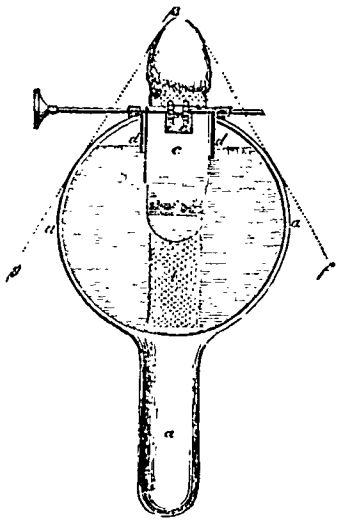
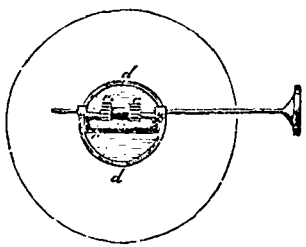


FIG. 263.



it is engaged in the process of combustion. When the wick is high, a large quantity of oil is decomposed; and when low, a small quantity in the same space of time; the supply of oil is, therefore, easily regulated.

By means of the stem *a*, the oil vessel can be placed upon any kind of foot. Besides the very unequal and constantly decreasing height of the surface of oil, another serious objection to this lamp consists in the extent and direction of the shadow which it throws, the conical space between βf and βg receiving no direct light.

Study-lamp.—In the common study-lamp, Fig. 264, the oil vessel *a* is more flat, and instead of being below, is situated behind, and at the side of the flame, so that its shadow falls much beyond the immediate vicinity of the flame, and in no way interferes with the light in front of the lamp. The greater part of the light passing upwards, is collected by the shade *k*, and is reflected down from every point of its inner surface. The inclination of the sides of the conical shade should be at an angle

FIG. 264.

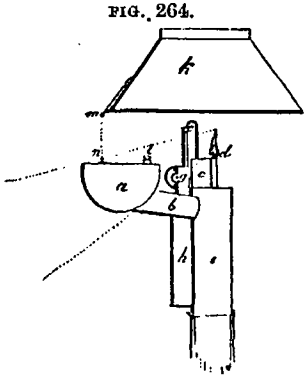
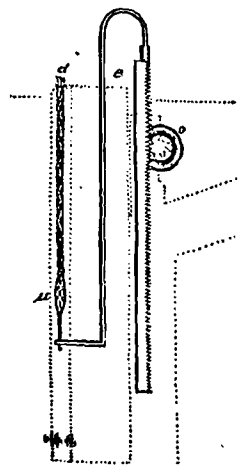
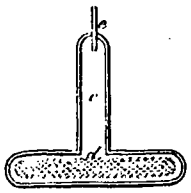


FIG. 265.



of about 60°. The shade can be turned on the support *m n*. The motion communicated to the wick *d* is from below, and not from above, as in the Worms'-lamp, where the pressure interferes with the supply of oil, and the flame is too much cooled by the proximity of the wheels. The clamp *u*, Fig. 265, which sustains the wick, is firmly connected with the rack *e*, which is moved by the pinion-wheel *o*. The rack and pinion are worked in a separate compartment *g h* from that containing the wick and the piece of metal by which it is held, both of which are in the burner-tube *c*, Fig. 266, and oil is supplied through the tube *b*; *i* is the enclosure round the burner.

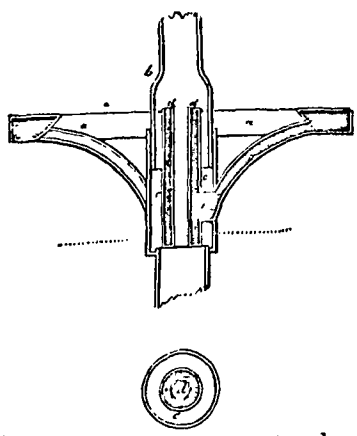
FIG. 266.



The motion of the wick by means of a rack and pinion is adapted to most lamps. The stopper *l*, which screws into the filling-hole, should be pierced in the centre that no empty space may be left as the oil sinks, and that the air on the outside may not depress the oil in the burner.

The Astral-lamp.—The astral-lamp, of which a sketch is given in Fig. 267, was constructed by Bordier-Marcet, with the view of preserving the oil level, and consequently the size of the flame as nearly constant as possible, by means of a very flat wide oil vessel, in which a large quantity of oil was spread on a very extensive surface, so as to form a very shallow reservoir. The shadow produced by the ring-shaped oil vessel is, in a great measure, rendered imperceptible by giving the inner surface the inclination of a cone, so that it may reflect the light down that impinges upon it. The burner is not peculiar to the astral-lamp, but is the well-known invention of Ami Argand, whose name it bears, and is by far the

FIG. 267.



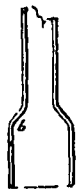
most important form of burner employed for illuminating purposes. The Argand burner, in use since 1789, consists of two metallic cylinders, *c* and *d*, Fig. 267, one within the other; the ring-shaped space between them, which is closed at bottom, contains the oil and the cylindrically woven wick; the latter is clamped between two rings, which are connected with a screw for raising and lowering the wick; the inner cylinder is open at both ends, admitting a current of air to pass upwards on the inner sides of the circular flame. The advantages of this arrangement are readily seen to consist in the more abundant supply of air to the surface of the flame.

We have already called attention to the dark central portion of a flame where combustion does not proceed on account of the absence of air. When this part of the flame is occupied by a wick, the wick cannot burn for the same reason, being surrounded by combustible gases, but without oxygen. In candles we have seen how this is obviated by the twist in the wick bringing the unconsumed portion to the side of the flame,—a plan which is not applicable to the wick of a lamp. The flat wick was an improvement upon the round massive strand of cotton, enabling a larger amount of oil to be consumed without smoke by increasing the surface in contact with the air. The Argand burner does this yet more effectually, but still the light is wanting in brilliancy, and if the quantity of oil be increased by raising the wick, a dense smoke is immediately produced.

Argand succeeded perfectly in overcoming this practical difficulty, by applying the happy idea of an artificial draught. The principle of the chimney was brought to bear upon the flame of a lamp in the following manner:—A gallery on the outside of the burner supports a straight glass cylinder,* through which the internal and external currents of air ascend with increased velocity in proportion to the height of the cylinder or chimney. A far greater amount of oil can thus be consumed during the same time without smoke, and a much more brilliant light is produced. Another advantage in the use of a chimney, not at first anticipated, is the great steadiness which it gives to the flame. A draught of air coming in contact with an unprotected flame, makes it flicker and smoke by the force and cooling action which it exerts. In Argand's burner, on the contrary, the supply of air to the flame is constant and self-regulating,

* The original chimneys used by Argand were made of sheet-iron, and arranged above the flame.

FIG. 268.



the heat of combustion itself being the motive power. Straight chimneys, however, produce too powerful a draught, which cools the flame; and a great improvement was made by Lange in contracting the diameter of the cylinder at a short distance above the top of the flame, as shown at *b* in Figs. 267 and 268. The current of air, which moves in the simple cylinder in a direction parallel to the axis of the cylinder, is interrupted by the shoulder *b*, and thrown at a certain angle into the flame. The supply of air is thus not only lessened, but brought to bear upon the part of the flame where it is most required. The use of chimneys is not confined to circular burners; they may be and are adapted to flat and semi-circular wicks.

Sinumbra-lamp.—When the astral-lamp is suspended from the ceiling of a room, the shadow of the circular oil vessel is thrown

FIG. 269.

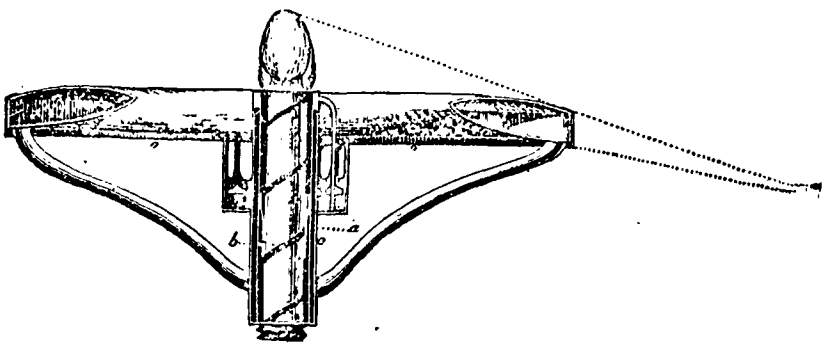
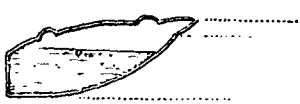


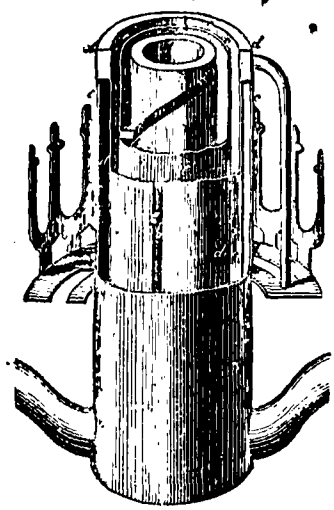
FIG. 270.



towards the ceiling; but this is not the case when the lamp stands upright on the table. By an ingenious modification in the shape of the oil vessel, Phillips has succeeded in his Sinumbra (*sine umbra*) lamp, Figs. 269 and 270, in rendering the shadow imperceptible even in the latter case. The oil vessel is constructed in the form of a flat wedge, the sharp edge of which is directed towards the flame in such a manner that two tangents, drawn from the apex and base of the flame to the outer edges of the vessel, will meet a few inches beyond them in *x*. No shadow beyond that point is consequently produced, and by employing a ground-glass shade, resting upon the oil vessel and surrounding the chimney, the light is equally distributed in all directions. The manner in which the

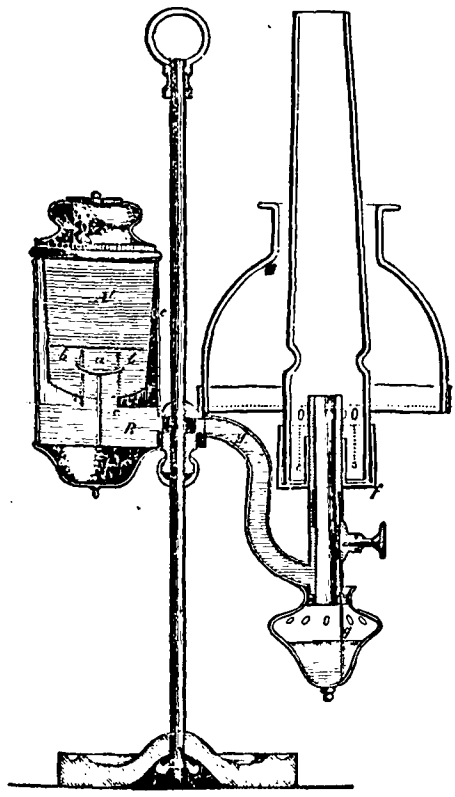
wick is moved in the sinumbra burner is original. On the outer surface of the inner cylinder *f*, Fig. 271, there is a deep spiral groove, in which the short pin *a*, attached to the wick-holder *e*, works up and down, carrying the wick with it as the latter is turned round. From its position in the burner, the wick-holder *e* cannot be reached with the fingers, and directly turned; but this is effected by the cylinder *d*, which, descending to the bottom of the burner, is connected with the gallery at the top, and moves with it. A slit in this cylinder *d*, admits a peg *b*, attached to the outer side of the wick-holder. Thus, when *b* is turned by means of the gallery, the motion is communicated to the wick-holder *e*, which, by the action of the peg *a* in the spiral groove *m*, is either raised or depressed, according to the direction in which *d* is moved.

FIG. 271.



The oil vessel being placed very nearly on a level with the burner in all the lamps yet described, renders it difficult to avoid an objectionable shadow, and numerous attempts have been made to remove the oil cistern either to a considerable distance above the flame—when its shadow would fall upon the ceiling of the room—or to a position much below the flame, when it would fall at the foot of the lamp. New difficulties arise, however, in the practical application of either proposition. When the supply of oil is situated above the level of the burner, its downward flow requires very accurate adjustment in order to prevent an excessive supply to the wick. This plan has, however, been carried out in the lamp shown in Fig. 272. The oil cistern *A* is a movable metallic vessel, capable of being closed at the bottom by a valve *a*, which slides between the regulating rods *b b*. When the vessel is inverted, the valve falls back, and leaves the aperture open for the admission of oil; the valve is then pulled up by the rod attached to it, the aperture closed, and the bottle again inverted in its place in the case *B* (as in the figure). The rod attached to the valve is, however, so long that, on reaching the bottom of the case *d*, the valve is again pushed up, and oil flows out, until it has risen so high in the case

FIG. 272.



as to cover the mouth of the bottle. The mouth of the vessel *A* being on a level with the burner, is filled by means of the tube *g*. The lamp has, in fact, two oil cisterns,—an under one, which directly feeds the burner, and an upper one, the inverted bottle, for the supply of the lower as the oil is gradually consumed. As long as the level of the oil in *B* remains unchanged, and the mouth of *A* consequently closed, no air can enter, and the stock of oil is sustained by the pressure of the atmosphere. When the lamp has been some time lighted, and the oil sinks below the mouth of the bottle, air-bubbles enter, and take the place of an equal bulk of oil, which flowing out raises the level in *B* until the mouth becomes again closed.

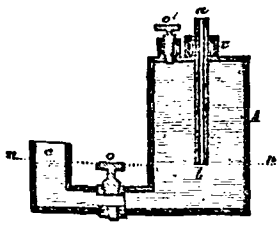
The other parts of the lamp are easily understood: *f* is the gallery for supporting the chimney (the peculiar form of which will be explained below), *q* is the vessel for the rack, and *e* is an aperture in the case for the admission of air into the interior.

In all lamps of this construction, from the peculiar arrangement of the oil cistern, the height of the oil in the burner will not be quite constant, but will alternately sink and rise again to its former height, while in the lamps previously described the constant sinking of the level of the oil prevents a regular supply being raised by the capillary action of the wick.

A simpler mode of regulating the supply of oil is represented in

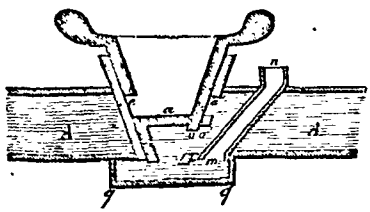
Fig. 273. A is a vessel constructed upon the principle of the common bird-fountain, with an open branch at e for the burner of a lamp, a stop-cock o, and an aperture o', capable of being closed by an air-tight stopper, by which the vessel can be filled with oil. An open tube $a\,b$ is inserted through an air-tight stuffing-box x at the top of the vessel, descending into the oil to the level of $n\,n$. The stop-cock o being opened, the oil ascends to the level n in e, air entering by the tube $a\,b$ to supply the place of the outflowing oil. As the oil is consumed at e, more air enters, displacing the oil from the upper part of the vessel A, until the fluid level is at $n\,n$ in both compartments. Any level can be obtained at e by raising or lowering the tube $a\,b$.

FIG. 273.



This same principle can be applied in a much more compact form to lamps with circular oil vessels, by means of Caron's stop-cock, Fig. 274. The conical plug of the cock is completely hollow, and the hollow space is separated into two unequal compartments by the bottom a. Two round apertures e and o, one in the upper and the other in the lower compartment, are placed opposite each other, and correspond with the apertures e' and o' in the socket of the plug. In the position of the cock represented in the drawing, the upper aperture e is closed, while the lower aperture o is in direct communication with the oil in the circular oil vessel $A\,A$. An open tube $m\,n$, the lower end of which is at the same level as the burner of the lamp, supplies air as it is required, in precisely the same manner as the tube $a\,b$ in Fig. 273. The supply of oil to the burner is furnished by tubes proceeding from the sunk part of the oil vessel $q\,q$. When the oil vessel requires replenishing, the plug is turned so that the upper aperture e shall be in communication with $A\,A$ through e', while the lower aperture o is closed, and thus all connection with the burner cut off.

FIG. 274.



When the oil cistern is placed at the foot of the lamp, or considerably below the burner, all shadow may be avoided, but the easy flow of oil to the burner, by reason of its own gravity, can no

longer be taken advantage of, and recourse must be had to mechanical agencies for raising the oil to the place of consumption. Both hydrodynamic and hydrostatic laws, as well as pure mechanical principles, have been brought ingeniously into practical operation for raising the oil in lamps of this description.

Girard's Lamp.—Girard's (fountain) lamp is constructed like the air-chamber of a fire-engine, or more nearly resembles Hero's fountain, Fig. 275. The principle involved in these contrivances consists in communicating the pressure exerted in one compartment of a vessel to any other distant cistern by means of compressed air, and thus forcing a liquid from its previous state of equilibrium to rise against the force of gravity. In Hero's fountain, the primary pressure is produced by the column of water *a* supplied from the vessel above it; the air enclosed between *c* and the lower bulb is thus compressed, and communicating the pressure to the surface of the liquid in *c*, forces it to a corresponding height at *d*. In Girard's lamp, these different compartments are closely packed together, as may be seen in the sketch Fig. 276, where the unimportant parts are left out. *A* is a reservoir of oil for supplying the column in the tube *a b*, by which the pressure is exerted; *B* the lower vessel with the enclosed air (*B'*), which conveys the pressure received from *a b* through the open tube *c d' d* to the vessel *C*, and in the first instance to the air *C'* contained in it. As long as pressure is exerted by *a b*, the air at *C'* will communicate it to the oil in *C*, which will rise in the tube *g h* to a corresponding height in the burner. This height will be determined by the height of the column of oil *a b*, which is liable to vary by the sinking of the oil in *A*, and by its rise in *B'*. To avoid the former source of irregularity, at least for the duration of an evening's consumption, the vessel *A* is furnished with a tube *e f*, upon the same principle as that described in the oil cistern at Fig. 273, by which contrivance the column of oil actually exerting pressure begins at the level of the aperture *e*, and all the oil above that level must be considered as a store for the supply of the column. The latter cause of variation is obviated by the cup *v*, into which the lower end of the tube *b* is immersed, and which is filled up to *s s* in a few moments by the oil flowing from *A*. Both contrivances

FIG. 275.

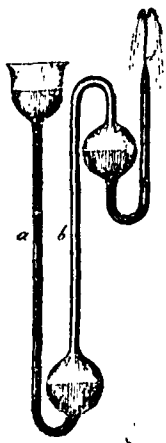
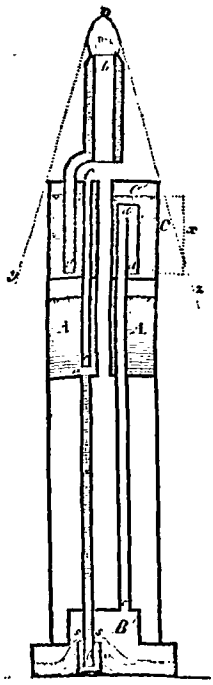


FIG. 276.



are effective, and a constant pressure, corresponding to the column *e s*, established, until the oil in *A* sinks below *e*, and has risen on the outside of *v* above the level *s s* in *B*. The pressure of the column *e s* would, however, raise the oil to a greater height than is desirable; and to avoid an excessive length of burner, the tube *c d' d* is bent like a syphon, by which means the oil in *g h* is made to rise as much less as *d* is below the fluid level in *C*. The pressure is first exerted to overcome the column of oil *x*, and it is only the excess that exerts an upward influence in *g h*; the result is, therefore, the same as if the elevation in *g h* was effected not from the level of the oil at *C*, but at *g*, for *g h = e s*.

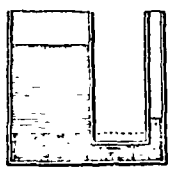
The lamp is charged by pouring in oil at *f*, which fills the compartments *B* and *A*, and where it is retained until required for use. The whole lamp is then inverted, when the oil that was at first in *B* flows through the tube *c d* into the compartment *C*, but does not flow out from the burner until, in the inverted position, it has passed the level of *g*. The oil in *A* is also prevented by the length of the tube *e f* from leaving the cistern *A*. When the oil begins to flow from the burner, the lamp is again placed upright on its foot, and is ready for use.

Future endeavours to employ the principle of Girard's lamp in a more suitable form for daily use will, perhaps, be successful; for the limited application which has been made of the lamp must be ascribed to its inconvenient shape. It is apparent that the working of the lamp is influenced by changes of temperature and pressure in the atmosphere; augmented pressure (rise of the barometer) and a low temperature diminishing the bulk of the air enclosed in *B* and *C*, and causing an augmented flow of oil from *A* towards *B*. A fall in the barometer, and a higher temperature, will produce an opposite effect, and cause the oil to flow from the burner. The effect of temperature is the stronger of the two, but both can be rendered imperceptible by proper means, at least for an evening. Another and a greater objection is found in the position and shape of the vessel *C*, from which, as may be seen by

the sketch, the burner is supplied with oil, the oil of *A* and *B* being only employed as fluid pressure. The diameter of *C* cannot be lessened without increasing its depth, in order to accommodate the requisite quantity of oil for an evening's consumption, and the height of the lamp then becomes inconvenient, while a wide vessel, placed immediately under the burner, throws a very objectionable shadow between *o y* and *o z*, which covers a much greater space than is occupied by the foot of the lamp. Lastly, the necessary apparatus and peculiar management required for filling the lamp have greatly interfered with its general introduction.

The Hydrostatic Lamp.—The equilibrium of fluid pressure has found another application in the hydrostatic lamps, which Fig. 277 will illustrate. Two liquids of different densities, and not miscible with each other, when placed in a vessel of the shape of Fig. 277, will balance each other at different levels, the difference varying with their respective densities. Thus a column of mercury only 1 inch in height will balance a column of sulphuric ether of 19 inches, or a column of oil of 14 inches.

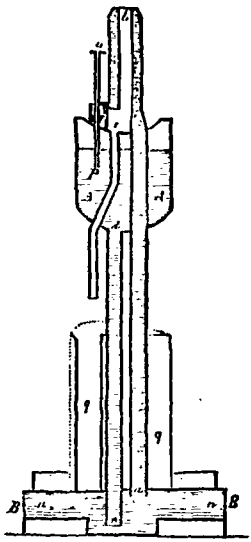
FIG. 277.



Numerous attempts were made to employ salt and water, syrup, honey, and mercury, as heavy liquids for raising the oil in lamps, but without much success, until Thilorier, in 1825, introduced a solution of white vitriol (sulphate of zinc), and an improved arrangement of the lamp. When it is borne in mind that the fluid producing the pressure must not affect the oil or the sides of the vessel (tinned iron), that it must not become solid at a temperature several degrees below 0° C., that it must be cheap, and have the proper density, the peculiar fitness of a solution of equal parts of white vitriol and water becomes apparent: a solution of this strength is 1.57 times denser than oil, so that a 10 inch column can support a column of oil 15.7 inches in height.

As the consumption of oil proceeds in the burner, and the column diminishes in height, the solution of zinc will sink to a corresponding level, and, in order to raise the oil to the original height, must itself be preserved at a constant level by a reservoir of zinc solution. The cistern *A* in the section of the lamp, Fig. 278, is solely for this purpose. Both the liquid columns terminate in a chamber *B* at the foot of the lamp; the column of oil in the tube *a b*, at the upper extremity of which the burner is situated, and the column of zinc solution in *e d*, above which is the cistern

FIG. 278.



A containing the supply. The flow is effected in the manner described in connection with Fig. 276, by means of the tube *o P*, through which the external air gradually enters as the solution sinks in *e d*. The height of the column must, therefore, be reckoned from *P*. The cistern *B* is completely filled by the two fluids, to the total exclusion of air. The tube *e d* is plunged into the lower solution of zinc (extending to *n n* in the Fig.), while the tube *a b* does not enter beyond the top layer of oil in *B*. From the time of lighting, and during the combustion, the level of the zinc solution *n n* progressively rises, until *B* becomes filled with it, and oil must be supplied by a separate funnel through the burner, which obliges the solution of zinc to return to its former position, while an outlet is afforded for the air in *A*. The tube *o P* (shown twice its proper size in Fig. 279), is intended for this purpose, having a conical appendage *h*, accurately ground to fit into *f f*, and luted into the lid of *A*. The drawing represents the tube raised for filling the lamp, air being admitted to the vessel *A* at the sides of the cone. On turning the tube round, the peg *g*, which is attached to *o P*, falls into a cavity in *f f*, and the valve is closed. The oil which overflows the burner falls into the concave lid of *A*, and passing through the tube *i i*, collects in the movable open vessel *q*, encircling the pipes *a b* and *e d*.

FIG. 279.

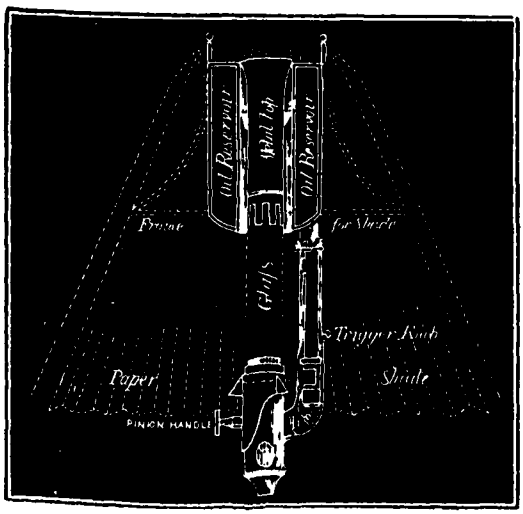
The supply of oil to the burner is not perfectly uniform, as the column of oil *n a b* is constantly diminishing in height by the rise of the zinc solution; but the diameter of *B* being large, as compared with that of *a b*, the difference of level never exceeds two or three lines during six hours' combustion, while in the Astral and Sinumbra lamps the oil level often falls one inch during the same time.

Thilorier's lamp combines many advantages, but they are accompanied by one very delicate peculiarity, which has precluded it from general use; it cannot be carried, nor indeed moved, without danger of being extinguished, for the slightest inclination, as in

the barometer, produces considerable fluctuations in the respective levels of the two fluids, and these fluctuations are always 1.57 times greater in the column of oil than in that of the zinc solution.

Parker's Lamp.—The thick consistence of crude whale oil offers such powerful resistance to the action of capillarity at the ordinary temperature of the air, that the oil cannot be burned in common lamps, unless it is previously rendered more fluid by the aid of heat. To effect this, a very ingenious form of lamp, upon the principle of the bird-fountain, has been introduced by Mr. Parker, called the Economic, or hot-oil lamp. The oil reservoir of this lamp, Fig. 280, is composed of a double cylinder surrounding the upper part of the chimney, which is constructed of metal, and slightly curved outwards at the top, so as to reflect heat upon the oil vessel. The oil thus warmed descends by an arm to the burner, where it is absorbed by the wick. The lower part of the arm attached to the oil vessel is furnished with a slide valve worked by a trigger, which cuts off the supply of oil at any moment, while the oil vessel may be removed from the lamp for the purpose of filling, &c. The oil is introduced by the valve, the oil cistern being inverted and filled each time the lamp is used, care being taken that no air remains in the vessel which would expand with the heat and cause an overflow of oil in the burner. The flame is regulated by raising or lowering the bell-mouthed glass chimney, which is supported at three points below, and moved by a rack and pinion. The wick is stationary, and cannot be moved as in other lamps; it is cut to a particular size by machinery, and a fresh wick is inserted every time the lamp is used.

FIG. 280.



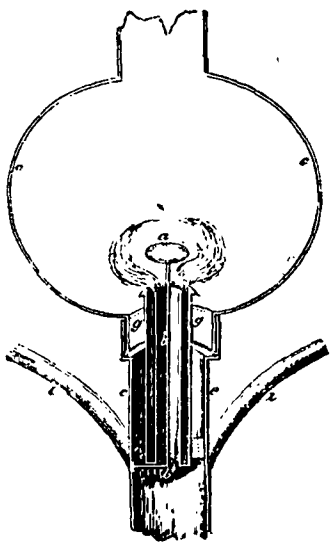
A paper or glass shade surrounds the whole of the upper part of

the lamp, according as the light is required to be thrown downwards, or uniformly diffused through the apartment. Dr. Ure reports most favourably upon the illuminating power of this lamp, which is superior even to that of Carcel, and when burning, southern whale oil fully deserves the appellation of "Economic."

The most recent improvements have aimed at regulating and directing the supply of air to the flame, so as to burn a greater quantity of oil in the same time, and produce a proportionally brighter light. These improvements are consequently chiefly connected with the burner and chimney.

Liverpool Lamp.—The burner in this lamp is the original Argand *g*, Fig. 281, through the central aperture of which a wire rises to a certain distance above the level of the wick-holder, supporting a copper disc or button *a* at the top of the same diameter as the wick. The proper distance between the disc *a* and the margin of the burner must be found, experimentally, by screwing the plate back and forwards until the greatest intensity of light is obtained. By this arrangement, the internal current of air is forced from its original perpendicular direction, and striking against the button *a*, is propelled at a sharp angle, nearly horizontal, against the flame, which is thus caused to assume a globular, instead of its ordinary cylindrical form, and (as is shown in the figure) is also brought more directly into contact with the external current. The form of the flame makes the peculiar bulging chimney *c* necessary, which is supported by the case *e* of the burner. Complete combustion, together with intense brilliancy and whiteness, characterise this flame; some want of uniformity is often observed in it, which, however, is not referable to the principle, and can be avoided by a proper regulation of the draught.

FIG. 281.



The lamps constructed by Benkler and Ruhl, in Wiesbaden, since the year 1840, depend likewise upon the plan of directing

a current of air upon a certain point of the flame. The apparent novelty of the invention, the surprising brilliancy and peculiarity of the flame, and the solid and elegant workmanship of the lamps themselves, led the public, at least for a time, to confound these advantages with the more essential one of an economical consumption of oil, and created in a short time such an enormous demand for this invention, that at the end of the year 1841, the manufactory at Wiesbaden turned out monthly, with sixty workmen, 2400 lamps. Some hasty experiments, published by the Physical Society of Frankfort-on-Maine, in favour of the invention, tended very much to increase this over-estimation of its value, which more accurate observations during the last few years have removed.

Fig. 282 is a sketch of Benkler's burner; Fig. 283 a cross section; and Fig. 284 represents the upper part separate. The

FIG. 282.

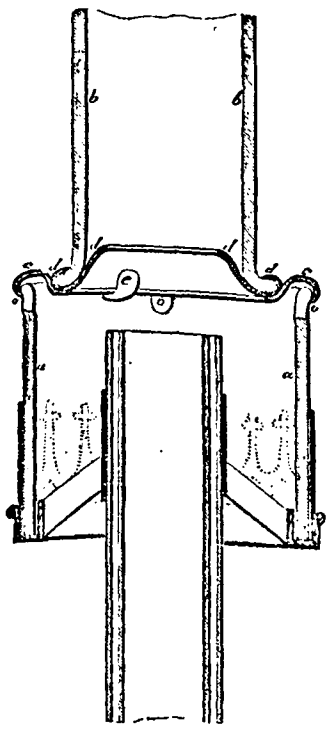


FIG. 283.

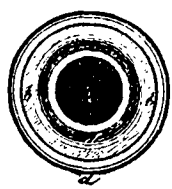
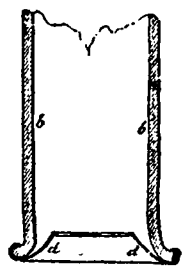


FIG. 284.



shoulder of the chimney is here formed at the junction of the narrower glass *b*, above the flame, with the wider glass *a*, below it. At this point the most important part of the lamp is placed, which consists of a conical ascending brass ring *d d*, with an aperture of the same diameter as the wick. This flat open cone is firmly attached to the upper glass *b*, by bending up its outer edge, Fig. 284. The connection of *b* with *a* is effected by a bayonet joint, two tongues *e*, on the lower margin of the cone *d*, corresponding with two cuts in the ring *c*, with which the margin of *a* is encircled. When, therefore, *d* is so placed upon *a* that the tongues and cuts correspond, a simple turn of *d* is sufficient to

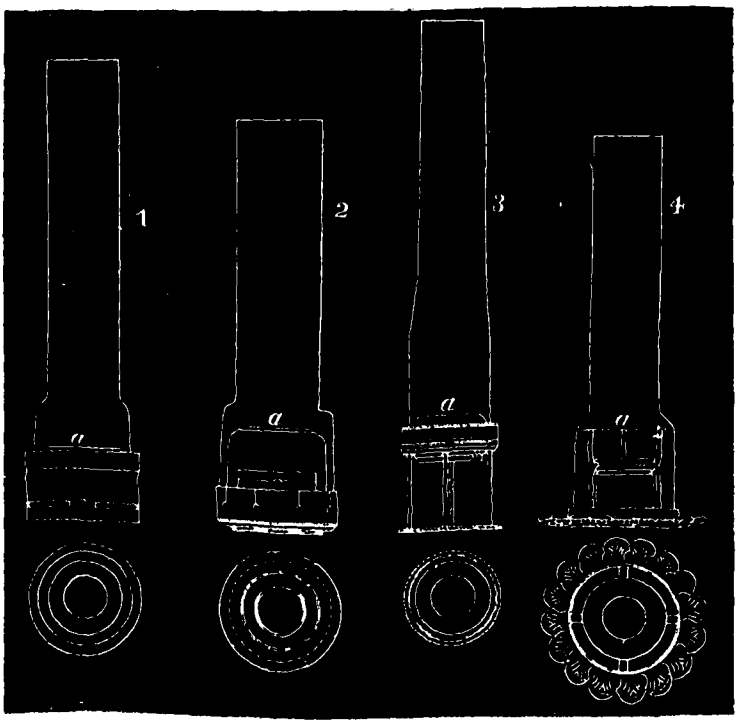
bring the tongues under the ring *c*, and thus secure the whole. The apertures *o o*, round the upper margin of *a*, tend to increase the draught. The principle of Benkler's lamp thus consists in a sudden contraction of the chimney, at a certain distance from the flame, produced by the insertion of a metallic ring or cone, with an aperture of the same diameter as the wick.

The action of such a contrivance is easily understood. The external and internal currents of air and the flame must pass through the aperture of *d*, where a rapid contraction results. The outer current is driven against the axis of the flame at a sharp angle, and thus forces the flame itself into the inner current, so that an intimate mixture of air is effected with the products of decomposition of the oil. The flame becomes narrower, and three times as long as usual, and by limiting the supply of air to the exact quantity which takes part in the combustion, and directing it upon the proper part of the flame, the highest and whitest brilliancy is attained, with a considerable evolution of heat. A perfectly white heat is produced, for, in consequence of the perfect combustion, the suspended particles of carbon are more intensely heated than in any other lamp. The chimneys stand well, notwithstanding the intensity of the heat. A very short portion of the flame, which produces the least light, is naturally situated below the cone *d*, but the longer and essentially luminous part is above, and throws a shadow from *d* downwards, which is perceptible in standing and hanging lamps, but is of no moment in the determination of the intensity of light, as it only occurs in the direction of the edges of *d*. As the cone *d* has no other object than that of producing a sudden contraction, chimneys are now made in one piece with an inward bend in the proper place, like that represented in Fig. 272.

Solar Lamp. — The lamps first introduced into this country by Mr. Smith, of Birmingham, under the name of Solar Lamps, are constructed upon precisely the same principle as those of Benkler and Ruhl. The main peculiarity in these lamps consists in the manner in which the air is caused to impinge upon the flame by the adaptation of a metallic or glass cone, represented at *a* in the figures below. The introduction of air at this particular part of the flame admits of crude cheap oil being consumed in the lamps, which would produce smoke if burnt in lamps of the ordinary construction. The combustion of this oil in the ordinary manner being attended by an

evolution of smoke and smell, indicating an imperfect consumption of the constituents of the oil, gives rise to the necessity for an increased supply of oxygen or air to that particular part of the flame where these unconsumed portions are evolved, to produce the inodorous and invisible products which alone should result from perfect combustion. The oil in the solar lamp is contained in an annular vessel, similar to that described at page 480, and the lamps are constructed in precisely the same manner, with the exception only of the burner. The first form in which the new burner was introduced is represented in section at 1, Fig. 285, and consists of a

FIG. 285.



solid metallic box fixed upon the circular wick-holder of the ordinary construction, so that the cone or contracted aperture *a*, shall be barely $\frac{1}{8}$th of an inch above the top of the wick-holder; this relative position is observed in all the burners. This form of cone box was found very inconvenient, becoming exceedingly hot and throwing a considerable shadow; it was, consequently, soon superseded by

that represented at 2, Fig. 285, in which the metallic box is very much diminished in size, and the cone is composed of glass, with a small ring of metal round the mouth *a*. This ring of metal is essential, as it is necessary that the aperture should be always of the same diameter, and glass cones can never be made with sufficient nicety to present at all times an exactly similar mouth. Messrs. Whitfield and Hughes subsequently replaced the solid box by the open skeleton cone holder represented at 3, Fig. 285, called the screw cone glass-holder, in consequence of the tall thin chimney being screwed on to the top of the holder. The last improvement is the plate cone glass-holder of Mr. Smethurst, represented at 4, Fig. 285, in which the metallic cone is replaced by a flat metallic ring fixed upon a skeleton support, the external edge of which fits closely to the glass chimney.

In the last form of burner, little or no external current impinges upon the flame from the outer sides of the cone or its substitute; but the flame is forced inwards so as to come more completely into contact with the current of air passing through the interior of the burner. The solar lamp has been extensively used in consequence of the low price of the oil which it consumes; it requires, however, considerable care and cleanliness in trimming,—the wick must be freshly cut every time the lamp is used, and the reservoir should be refilled with oil.

Several of the contrivances already described supply one or other of the essential requisites of a good lamp, but generally at the expense of some other equally important condition, and none combines all that is necessary to make a perfect lamp.

The *mechanical, pump,* or *pressure lamps,* in which the oil is raised to the wick by mechanical means, have been so much improved of late years as nearly to supersede all others. The simplest example of these, is the pump lamp, with a flat wick, much used in the south of France, but not in this country: the pump is worked by hand, in a very imperfect manner, the piston being constantly forced upwards by the tension of a spiral spring. As soon as the piston rod, which forms the ascending tube in connection with the burner, is forced down by overcoming the power of the spring, the descending piston forces the oil in the cylinder to rise through the tube to the burner. When the stroke is ended, the elasticity of the spring brings the piston to its former position, and the cylinder is again filled, but the pump requires to be worked at very short intervals. In lamps of this kind, with double draught,

the burner is fixed, and the piston is worked by a handle at the side of the ascending tube. The uniform working of these lamps depends upon the care which is taken to supply the oil that is consumed by repeated use of the pump. If this is only done at long intervals, the flame will vary from its utmost intensity to a very dingy light.

It has already been mentioned, in speaking of the general principles of lamp and candle illumination, how the lowering of the oil level, as combustion proceeds, interferes with the regular function of the wick, and consequently diminishes the brilliancy of the flame. The lamps with a supply upon the principle of connected tubes, are subject to this evil in its full extent; those with an inverted bottle or similar arrangement are also influenced by it within certain limits. In the former, the brilliancy rapidly diminishes; in the latter it becomes less, but returns to its former condition at regular intervals.

Carcel's Clock-work or Mechanical Lamp.—Carcel was the first to carry out the idea of pumping up the oil from the foot of the lamp to the wick, by simple machinery like that of clocks, and in such quantity as to exceed the quantity consumed during the whole period of burning. The invention of his clock-lamp, in the year 1800, is without precedent, with reference to the uninterrupted and perfect supply of oil to the wick. While in other lamps the burner contains a stationary column of oil, the level of which is either being constantly lowered, or, after having sunk to a certain extent, is re-established from time to time, the oil in Carcel's burner forms a constant ascending current, which always supplies the wick with more than it can possibly require, the unconsumed portion flowing back to the cistern over the edges of the burner.

Carcel brought his invention to such perfection that only unimportant points connected with the works and the pump were left for the improvements of his successors, Gagneau, Nicod, Careau, and others. Figs. 286 to 288 show sections of Carcel's lamp, with Penot's improvements. The chief parts of the lamp are arranged as follows. The case for the works *B*, and the space *A* for the stock of oil, are enclosed in the foot of the lamp. The stem of the column contains the ascending tube *b*, which separates above (over the capital) into a forked appendage or crutch, to which the burner, with its two concentric tubes *e e*, are attached. The burner and the ascending tube are thus connected with *A* by means of the pump. The pump is called after its in-

FIG. 286.

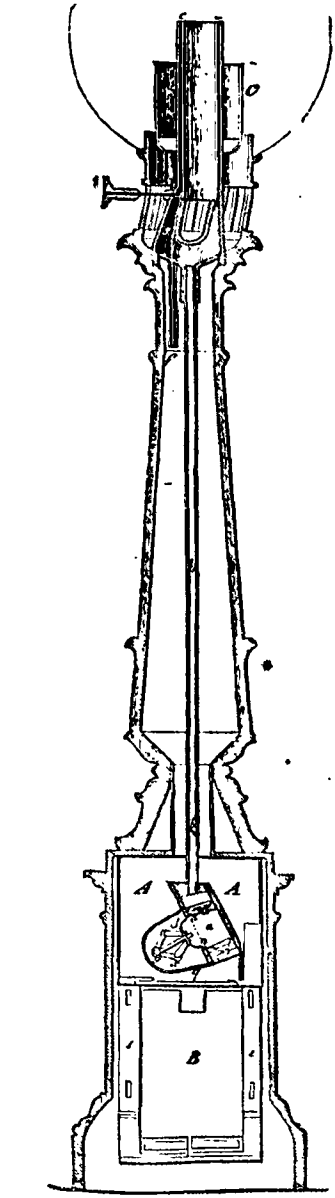
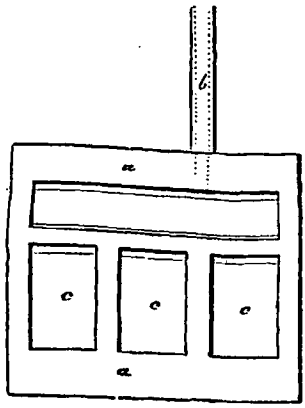


FIG. 287.

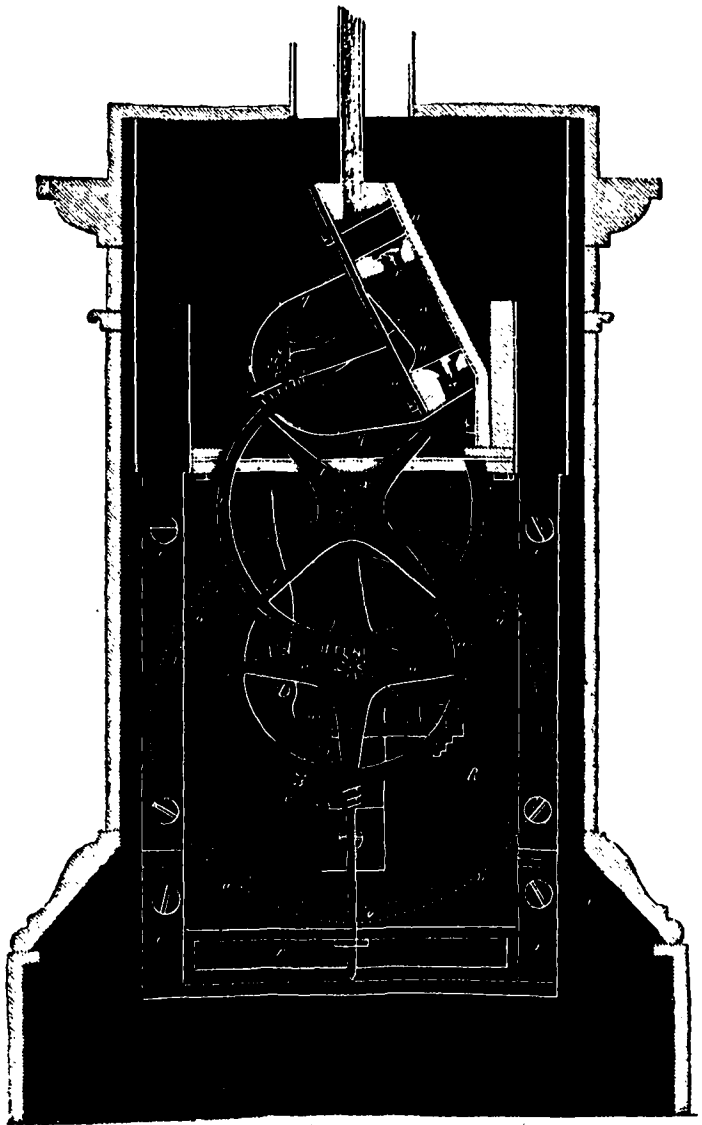


ventor, a *Priest-pump*, and is represented in a more simple form in Fig. 289. The box *x* is closed at the top by a piece of elastic cloth or leather, in the middle of which a piston rod *f* is fixed. By the upward and downward motion of this rod, an alternate expansion and contraction is effected in *x*. In the first case, the valve *s* is opened, and oil enters *x* from *r r*; in the other, through the valve *s'*, oil passes from *x*, and is raised in the tube *t*. The motion of the cloth or leather acts, in short, in the manner of the cheeks and muscles in drinking and blowing. To prevent obstructions which would result from the presence of impurities, the oil, while still in *A*, and before entering the pumps, is passed through a metallic sieve with fine holes *q*, which surrounds the whole of the front part, including the entrances to the valves below.

In order to ensure uniformity of action, the quadrangular box contains three simple Priest-pumps

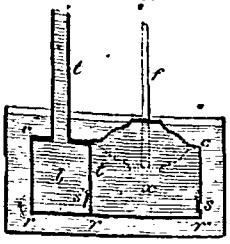
c c c, made of gold-beater's skin, each of which is engaged, with reference to the other two, in performing some different function

FIG. 288.



at the same moment. Each pump has two valves, an entrance valve (the under one in the figure) and an exit valve (the

FIG. 289.



upper.) A separate chamber *a* is connected with each, while the space for receiving the oil above the exit valve is common to all. The three short piston rods work upon three crooked arms $\beta\,y\,x$ on the same axis, but in different directions. One pump is thus always engaged in forcing, while the second is sucking, and the other mid-way between the two. The chamber *A* (Fig. 286) is completely closed below, or in the direction of *B*, with the exception of a stuffing box, through which the crooked pin of the axle is moved. The wheel *t* passes under a box placed at the side, in which this stuffing box is situated. The iron frame work *i i* gives steadiness to the works in *B*. Motion is obtained by the spring wound up in the case *o o o*, which is furnished with cogs. The cogs of *o o o* set the toothed wheel *t* in motion by means of *x*. The wheel *t* catches the second cog *y* above, which is upon the same axis as the piston rods, and thus the pumps are set in motion. The wheel *t* likewise works into *z*, which, by means of the cog wheels *u* and *v* working the endless screw on the axis of the fly-wheel *p*, sets the latter in motion. At the very bottom, on one side of the foot of the lamp, is a small bolt, which, when pushed forward, catches the fly wheel, and either stops the works when in motion, or sets them going when it is pulled back, and the spring has been wound up.

The stop wheel *W* is used for winding up the machine with a key.

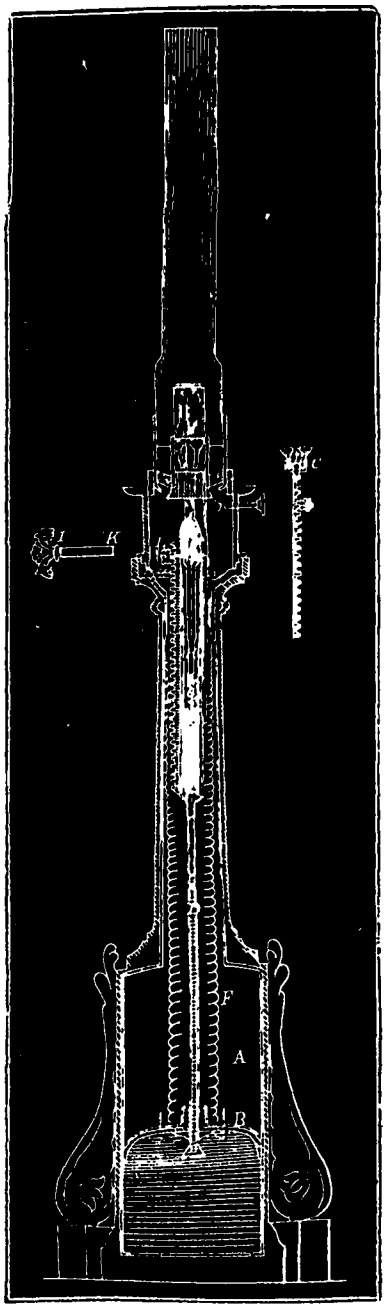
The rack *g* (Fig. 286), with the wick-holder, works below the crutch of the ascending tube, in the case *f*.

Experience has shown that the whole arrangement of the works is not so tender and brittle as might at first sight have been supposed.

The overflow of oil from the burner renders it necessary to screw up the wick somewhat higher than in common lamps, which is accompanied with the great advantage of the flame being raised considerably above the edge of the burner. Thus less heat is conducted from it, and it burns more perfectly, producing no carbonaceous matter on the wick and about the edge of the burner, which, in general, so materially interferes with the regular flow of oil.

Carcel's invention would certainly have been valued as highly as Argand's had been sixteen years previously, if a less expensive and more suitable form for general use could have been employed.

FIG. 290.



It has often been suggested, both before and after Carcel's invention, that the complicated clockwork might be substituted by a simpler mechanical power, such as the weight of a falling body or the tension of a spiral spring. Joanne, Franchot, Houghton, and others, endeavoured to carry out this idea, but the difficulty of regulating the *acceleration* of the fall, or the *diminution of the force of the spring*, to the uniform demand of the burner, was so great, and the complex arrangements acted so imperfectly, that the lamps fell into disuse. In Meyer's Elliptic and in the French Moderator lamps, the difficulties, however, appear to have been successfully surmounted.

Elliptic Lamp.—In this lamp a spiral spring, acting on a piston, is the motive power, and the constant flow of oil to the wick is regulated in an ingenious manner by means of a tube of narrow bore. Fig. 290 represents an entire section of the lamp. The oil cistern *A* forms the foot of the lamp, which being of a cylindrical shape, admits of a leathern piston, or valve *B*, being worked up and down by rack and pinion, seen at *L*, while a coil *F*, of strong iron wire, fixed at the top to the solid stem of the lamp, exerts a constant pressure on the piston, so long as it

occupies any position above the bottom of the oil cistern. The tube *D*, which opens at the bottom in the shape of an inverted funnel, and ends in a disc pierced with holes, supplies the oil to the burner, and passes in an air-tight manner through a stuffing box in the piston *B*, and can thus be moved with ease, the piston remaining stationary. The tube *D* is widened above on approaching the burner, and encloses a fine silver tube several inches long and $\frac{1}{30}$th of an inch internal diameter, which is surrounded by a cap of fine gauze, made of copper wire tinned, to prevent corrosion. The gauze prevents any solid particles, mechanically mixed with the oil, from being carried up into the silver tube, which would impede or altogether stop the passage of the oil. The whole of the oil must pass through the silver tube before reaching the burner, and the friction thus exerted counteracts the pressure of the spiral spring. The small silver tube thus regulates the lamp, and is so proportioned in length and bore as to permit a slight excess of oil to be raised by the spring to the burner, whence the unconsumed portion flows back on to the top of the piston *B* in the oil vessel *A* at the foot of the lamp. The lamp is filled with oil by slightly raising the whole interior portion from *L*, and pouring oil through the stem to the cistern below; the oil thus rests in the first instance on the top of the piston. The whole interior portion of the lamp is then wound up by the key *I K* and the rack work *L*, until the top of the cistern prevents the piston *B* from ascending higher. The tube *D* and the burner, &c., attached to it, are now forced down by the hand through the stuffing box. The oil, during the ascent of the piston, escapes from the upper space *A* over the leather flange or valve which intervenes between the piston and the cylinder, and is so constructed as to prevent the oil returning to the upper space when the piston is depressed by the spring. The oil now below the piston is hence forced, by the force of the spring pressing upon the piston, to ascend through the tube *D* to the burner.

The friction exerted by the silver tube, impeding the ascent of the oil, is so proportioned to the tension of the spring, that eight or ten hours are required before the piston descends and the oil reservoir is exhausted.

Moderator Lamp.—The French Moderator Lamp (Fig. 291) is similar in principle, but of somewhat different construction. The whole body of the lamp forms a reservoir for the oil and at the same

time the barrel of the pump, in which the piston A is worked by a spiral spring firmly attached to it and to the upper part of the

FIG. 291.

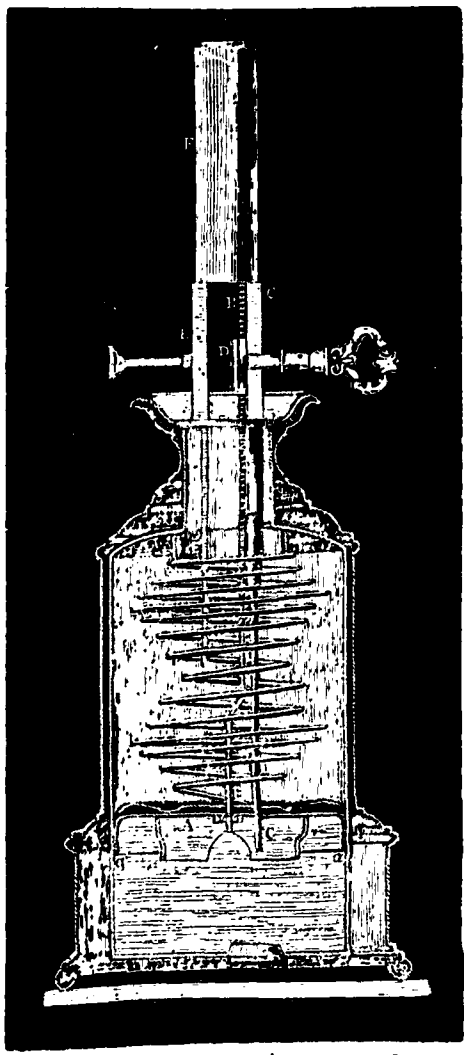


FIG. 292.

barrel. The piston A pressing upon the oil below it, forces the oil to ascend in the tube C to the burner. In order to regulate the supply of oil, which would be excessive when the spring exerted its greatest force, and gradually diminish as the piston approached the bottom of the barrel, the ascending tube C (Fig. 292) is

constructed in two pieces, one fitting into the other. The lower part is firmly attached to the piston below, which it opens, and with which it slides up and down. The upper part is fixed to the burner, and remains stationary, forming a kind of sheath to the lower, as it rises and falls with the piston. A small rod or wire G G (Fig. 293) is placed in the ascending tube C, extending just as far as the lower and narrower portion, when the latter is drawn out to its full extent. The oil in rising is thus forced through the annular space between the wire and sides of the narrow tube, and the friction exerted retards its upward progress in proportion to the extent of the narrow passage, which varies with the height of the piston. When the piston is wound up by the rack and pinion B D, the spring will exert the greatest amount of pressure, the wire G G will occupy the whole interior of the narrow tube, and the oil must travel through the corresponding annular space, and its upward flow be proportionally retarded: the length of this space decreasing with the descent of the piston and diminished force of the spring, the oil has less resistance offered to its ascent as the pressure diminishes. When the size of the wire, or moderator, is properly adapted to the bore of the tube and the force of the spring, the amount of oil supplied to the burner does not vary during the whole time the lamp is in action. The whole of the oil thus raised to the wick is not consumed, but a portion flows over the burner and falls into the barrel above the piston, where the fresh supply of oil is also introduced until the whole of the spring is immersed. When the piston is raised, a vacuum is produced below it, and the oil above escapes to the under side over the flange of leather *a a*, which, being attached to the piston, intervenes between it and the barrel of the pump.

FIG. 293.

Camphine Lamps.—Volatile oils are applicable as illuminating material, when they can be obtained at a sufficiently low price, but they require special management, and, more particularly, a well-regulated and abundant supply of air, to consume completely the very large quantity of carbon which enters into their composition. When employed instead of oil in lamps of ordinary construction, they evolve a great quantity of smoke, and much of the oil escapes combustion.

88161

It is only within the last few years that oil of turpentine or camphine has been successfully introduced as a fuel for lamps, and it is by applying the principle of the solar cone in an extended manner that this highly carbonaceous substance is completely and conveniently consumed. The method of procuring oil of turpentine by distillation from the crude resin has already been described, but the oil obtained from the first distillation must be repeatedly rectified over chloride of calcium, or some similar substance, in order to separate every trace of water. The oil contains:

88.46 carbon
11.54 hydrogen

100.

which corresponds to the formula $C_{10}H_8$. It is obvious that a substance containing so large an amount of carbon must necessarily be a powerful illuminating body, but will require a very large quantity of oxygen or air for the entire consumption of the two combustible constituents, and at the same time the order of combustion must be carefully attended to, that the full amount of light may be obtained.

Vesta lamp.—Young was the first who applied the increased draught of air produced by a cone to the flame of oil of turpentine. The burner of Young's Vesta lamp is shown in Fig. 294. It is an ordinary Argand burner with a Liverpool button, for deflecting the internal current of air, which enters by a space left open near the pinion handle, and passes through the centre of the burner to the inner side of the flame; the wick tube is encircled by a metal cone, which only rises in this case to the same level as the burner, and between the two a current of air impinges upon the flame at that part where it is expanded by the button and the internal current. The air, in passing up the inner sides of the contracted chimney, is also deflected inwards upon the flame. The entire burner is screwed upon a glass vessel containing the oil of turpentine, and completely insulated by a ring of wood or other non-conducting material; no metallic tube passes through the spirit to supply air to the interior of the flame, as it was supposed that this would become too strongly heated and give rise to acrid and offensive fumes from the volatile spirit. This lamp, when properly managed and supplied with pure camphine, gives an excellent light, much superior to that produced by any oil lamp;

but if attention is not paid to the management, or the camphine is not pure, it frequently evolves a strong smell of turpentine, pro-

FIG. 294.

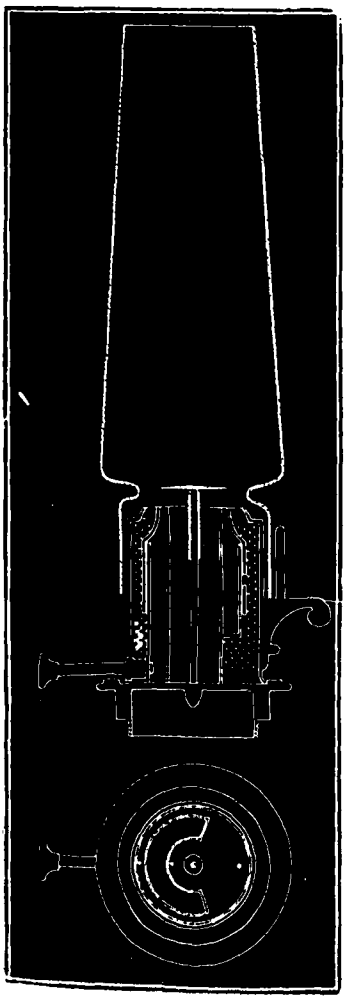
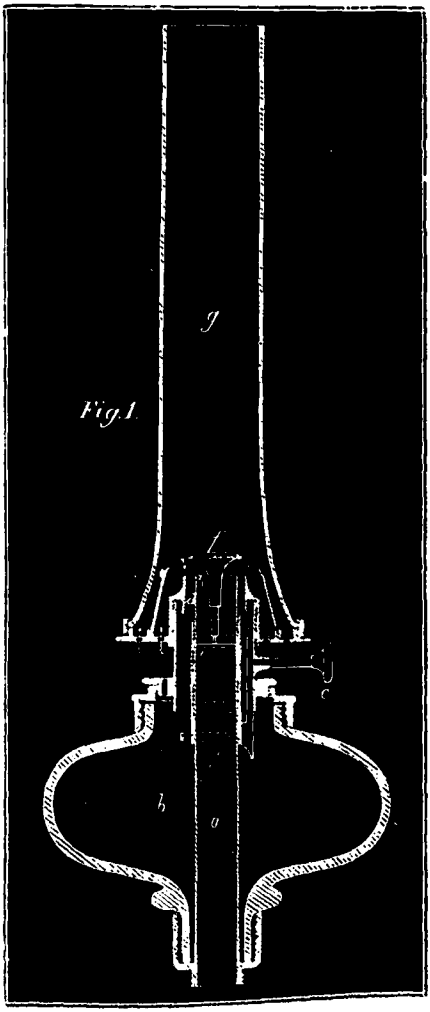


FIG. 295.



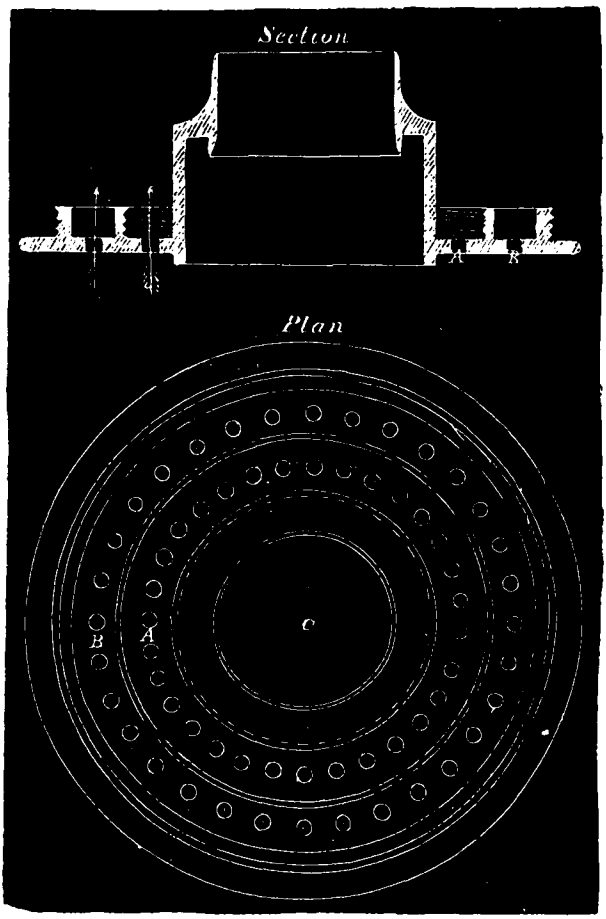
ducing headache and other disagreeable sensations, or large flakes of soot escape unconsumed.

Gem lamp.—The lamp which consumes camphine most perfectly is the Gem, patented by Mr. Roberts, a section of which is shown in Fig. 295. It differs from Young's lamp, in the mode of de-

flecting the currents of air, and in allowing the Argand tube, which supplies the internal current of air, to pass through the reservoir containing the oil of turpentine. In Fig. 295, *a* is the tube supplying the internal current of air which passes through the reservoir *b* to the burner *d*, with which it is in metallic connection, and it is found that the temperature of the turpentine does not exceed that in Young's lamp by more than 1 or 2 degrees. The temperature of the spirit in both cases is from 10 to 15 degrees above the temperature of the surrounding air, and this appears to be necessary for the proper action of lamps of this description. The button *f*, which deflects the inner current upon the flame, and forces it to take an outward direction so as to come into contact with the first outer current, has the form of an inverted cone, and the deflection of the air is consequently not so abrupt. The supply of air to the in and outside of the cone is regulated by a series of holes drilled in the brass gallery, and the number and size of these holes are proportioned to the size of the burner, or to the quantity of air admitted through the internal channel.

Fig. 296 shows a plan and section of the gallery: *C* is the space occupied by the inner current of air, deflected outwards by the button, *A* the first series of holes admitting air to the interior of the cone, and *B* the series of holes through which the air passes to the exterior of the cone. The circle *A* has 32 holes $\frac{1}{12}$th of an inch in diameter; the circle *B* has also 32 holes $\frac{1}{10}$th of an inch, these dimensions having been found by experiment to be most advantageous for a burner of the size represented in the drawing. The cone *e*, Fig. 296, in this lamp rises above the level of the wick tube, so that the inner current of air and the first outer current meet the flame below the button at the point represented by the meeting of the two arrows, Fig. 296. The outer current of air, passing through the holes in the circle *B*, meets the flame at a higher level, and ensures the complete combustion of any products that may have been unconsumed after passing the point where the arrows meet. The quantity of air admitted depends upon the height of the chimney, which therefore requires attention. The proper quantity of air, and the direction of the different currents to those parts of the flame where they are most beneficial, appear to have been attained more perfectly in the Gem than in any other spirit lamp yet invented. A Gem lamp of the larger form is reported to give a light equal to 20 wax candles; the light from one of the smaller size is equal to 13 wax candles.

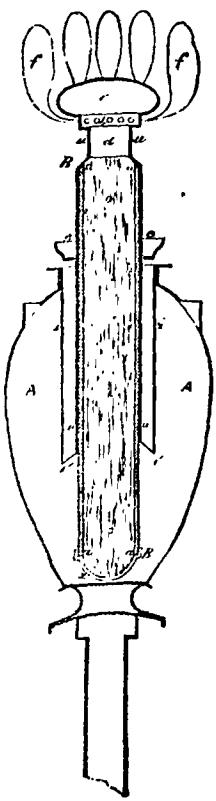
FIG. 296.



Vapour Lamps.—In many parts of the continent, where the excise duty upon spirits of wine is small, this substance may be mixed with volatile oils rich in carbon so as to reduce their percentage, when they become far more manageable as illuminating substances. In the lamps which consume this highly combustible and volatile fuel, as in those intended for coal-tar naphtha, the liquid is generally converted into vapour before it reaches the burner, and they are therefore very aptly distinguished as *vapour* or *self-generating gas* lamps.

Lüdersdorff's lamp.—In Berlin, for instance, instead of burning pure oil of turpentine, Lüdersdorff has constructed a lamp for consuming a mixture of this spirit with 4 parts of strong alcohol, of at least 90 per cent. A greater amount of water in the alcohol would cool the flame too much, and the oil of turpentine would be imperfectly held in solution. The carbon, originally amounting to 88 per cent, or 8 times the quantity of hydrogen in pure oil of turpentine, is diminished in this mixture (called illuminating spirit) to 63 per cent, or 3 times the hydrogen, which is a less percentage than is contained in oil or tallow. Much less light will, of course, be evolved from a certain weight of this spirit as compared with pure oil of turpentine, but this is compensated, although at some cost, by the greater rapidity with which the combustion proceeds. Lüdersdorff's lamp is shown in Fig. 297, and will afford a good example of the method employed for burning volatile oil in vapour lamps generally.

FIG. 297.



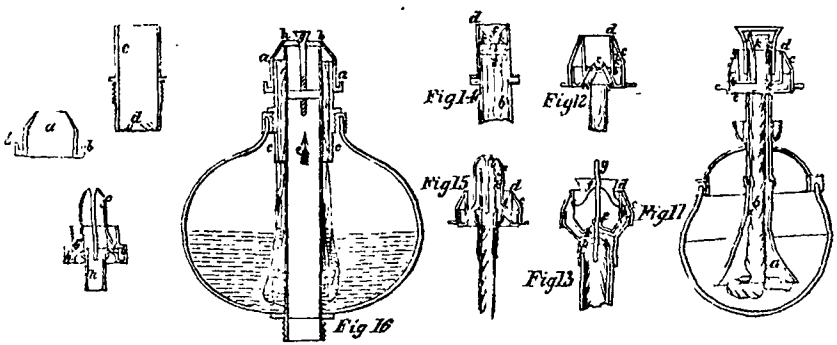
A is the vase for the illuminating spirit, into which the burner *B* descends almost to the bottom. It consists of a straight, pretty wide, metal tube *a a*, fitting tightly into the burner tube *u u*, and enclosing a loose cotton wick *o o*, fastened down by the semi-circular piece *x*. About two inches above the vase *A*, the tube *a a* is contracted and ultimately closed by the knob *c*, which is the actual burner; at the base of the knob *c*, from ten to twelve holes *b*, one-fourth of a line in bore, are made in a circle at equal distances from each other. When the lamp is to be used, common spirit of wine is ignited in the cup *e e*, to volatilise the illuminating spirit in the upper part of the wick. As soon as the vapour issues from the apertures *b*, it is ignited, and forms the flames *f* which surround the knob *c*. The high temperature of the metallic knob is then amply sufficient to keep up the evaporation, even at the distance of *c* from the wick, and the lamp continues to burn by itself. To protect *A* from the action of the burner, which gradually becomes heated, the latter is

surrounded, to the depth of three inches, with a wide case *i i*, which, being filled with air, prevents the heat communicating directly with the spirit in *A*. Lamps of this kind give a costly but brilliant light, and are free from all the inconveniences attending the use of common wicks. The French Gasogène lamps are constructed upon a precisely similar principle, with some slight difference in the mechanical details, and coal-tar naphtha may be substituted for the oil of turpentine in the illuminating mixture.

Mansfield's lamps.—Pyroxylic spirit and acetone have been proposed by Mansfield as means of diminishing the percentage of carbon in the various hydrocarbons obtained at different stages in the process of the rectification of coal-tar naphtha. One part by measure of hydrocarbon to two parts of wood spirit, or to four parts of acetone, are found useful mixtures, although the relative proportions must be varied with the nature of the naphtha and the mode of consumption. The more air is admitted to the burner, the greater may be the amount of hydrocarbon to produce light without smoke. These mixtures require no distillation previous to being burned; but a peculiar form of burner is found suitable for their consumption, yielding a film of flame, the thickness of which may be adjusted by the movement of one or more parts of the burner. The burner is also constructed to heat the liquid conveyed to it, and convert it into vapour before it escapes from the slit where it is ignited.

The several drawings on Fig. 298 represent lamps and burners

FIG. 298.



adapted for consuming these illuminating liquids. In Fig. 11 a twisted wick is employed for raising the liquid to the burner; in Fig. 16 a hollow cylindrical wick performs the same office, while the cylindrical channel *e* admits air to the interior of the flame.

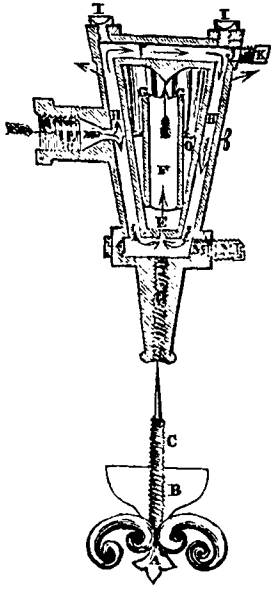
In Fig. 11 *a* is a cone or inverted vessel covering the lower part of the wick, and preventing evaporation from that part which is above the level of the fluid in the reservoir.

Figs. 12, 13, 14, and 15 represent different forms of burners adapted for lamps upon the principle of Fig. 11. In all of these *b* represents the wick, which may be of twisted cotton; *c*, a moveable cone or cylinder, by moving which the size of the slit or orifice *d* may be adjusted; *e*, passage or passages by which air is admitted to the centre of the flame; *f*, part which, being heated by the flame, conducts heat to the wick, and causes the evolution of vapour. In Fig. 11 this part *f* is a hollow button, or cap, surrounding the top of the wick; in Fig. 13 it is a solid button, through which, and through a tight collar in the top of the wick-holder, a rod or wire *g* may be made to pass so as to reach the wick; in Fig. 14, *f* is a solid button attached to a pin, which passes through a cross piece and touches the wick; and in Fig. 15, *f* is a cap, which, with the rest of the burner, is moveable upon the wick-holder, on which it slides by means of the collar *h*; *k*, a chamber, from which, and tubes through which the vapour is conducted from the wick to the burner. Fig. 15* shows the moveable cap or burner which slides upon the wick-holder, the exterior moveable cone having been removed.

In Fig. 16, *a* is the exterior moveable cone which slides tightly on *c*, the wick-holder, to which several hooks are attached (as at *d*) for supporting the wick; *g*, a button for collecting heat from the flame and transmitting it to the wick through the inner cylinder; *h*, the slit from which the flame issues.

Holliday's lamps.—These vapour lamps are intended to consume rectified coal tar naphtha mixed with air: the mode of obtaining the naphtha will be described in connection with the manufacture of gas. The construction of the lamp to be used in dwellings is upon much the same principle as that of Lüdersdorf. The burner requires heating with a red hot iron until naphtha vapour issues from the wick; this vapour is then, by the peculiar construction of the burner, mixed with air before passing out at the jets where it is ignited. The caution required in using this lamp, from the highly combustible nature of the fuel, and the rather troublesome management which it demands, have prevented the general introduction of what would otherwise be a very economical source of a brilliant light. These remarks, however, do not apply to another form of lamp intended for out-door purposes, and which

FIG. 299.



has been found exceedingly useful in sheds, workshops, railway stations, and wherever freedom from sparks of fire is a desirable object. A section of the burner of this naphtha lamp is shewn in Fig. 299. The spirit is supplied from a reservoir by means of a tube and regulating stopcock to the burner at A, where it flows into the internal passages H H. The burner is, in the first instance, heated over a flame, when the liquid soon becomes converted into vapour, which escaping through an extremely fine aperture at E, and passing up the centre air tube F, is deflected, by the inverted cone above the wires G G, which separate it into several jets of flame. Screws are inserted in the apertures I J M, which, when removed, enable the internal passages to be cleaned, while the bottom screw B C, with its pointed extremity which passes up into the aperture E, regulates the current of vapour.

Beale and d'Hanens' lamps.—For the coal districts of England and Belgium, where an abundance of coal tar naphtha, or oil of coal tar, is obtained, Beale and d'Hanens have also contrived lamps without wicks, in connection with a blast of air. In Beale's lamp, but not in d'Hanens', the current of air passes through the naphtha, and becomes saturated with it. The former produces a flame from six to seven inches high, when worked with a double current of air, whilst that of d'Hanens', from a knob surrounded by ten holes, in the manner of Lüdersdorff's lamp, throws out a crown, consisting of as many single flames. Both lamps produce dazzling white flames, which, in themselves, are without smell, and only disseminate the penetrating odour of coal tar naphtha for a few moments after they have been extinguished. They are well adapted for lighting streets and out-door workshops, but not for rooms.

Mansfield proposes to burn the more volatile portions of coal tar naphtha by mixing them with a current of air produced either by mechanical means or by a simple chimney draught. Those portions of coal tar naphtha which distil at a temperature from about

80° to 100° C. (176° to 212° F.), and which he calls *crude benzole*, are most applicable for this purpose. The mode of obtaining these hydro-carbons sufficiently pure for illuminating purposes will be described below. Many combustible and incombustible gases, and even common air when simply passed through these liquids at ordinary temperatures, take up a sufficient quantity of the hydro-carbon to afford an illuminating gas which may then be burned in the ordinary manner, or with some slight differences in the form of burner. One of the lamps for burning a mixture of benzole and air is represented in Fig. 300: *A* is the benzole reservoir connected with the burner *B* by the tube *c c*, which is here represented at its lower part as a segment of a double cylinder, so as to leave one side open for the approach of the hand, and of air, to *g* and *f*, and above, as an entire double cylinder, which forms part of the burner. *d d* are cotton wicks suspended on a wire frame for absorbing the liquid benzole *e* and enveloping the mouth of the wide tube *b*, through which air is supplied during the combustion by the action of the chimney. The burner is an Argand, with a central aperture *f* and an outer circular channel *i* for the admission of additional air, both of which channels can be partially or completely closed by slides at *o* and *o'*; *l* is the clamp-support for the chimney, which can be raised or lowered on the burner so as to regulate the draught. The inner wall of the outer air passage *k* forms the external moveable wall of the burner, and by its means the size of the annular jet or aperture *n* may be adjusted. *a* is a pipe with a mouthpiece, for blowing air into the vessel *A* when the lamp is lighted; as soon as a flame is produced, the chimney is then sufficient to cause a

FIG. 300.

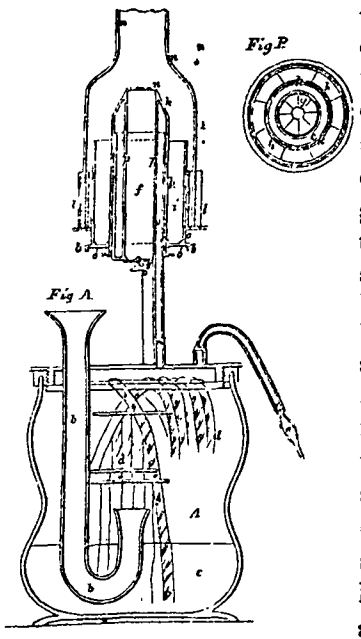
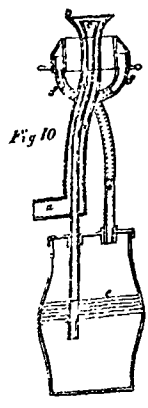


FIG. 301.



current of air to pass down the tube *b*, and become saturated with benzole vapour.

Fig. 301 represents an arrangement for consuming, by the aid of a current of air which is heated by the burner, hydrocarbons less volatile than benzole, and not yielding sufficient vapour to a current of cold air. *a* is the tube by which the air ascends to *b*, the button or chamber so placed as to be heated by the burner. *c* the tube (which may be contained through part of its descent within the tube *b*) by which the heated air descends to the reservoir or evaporating vessel *e*; *f* the tube and its branches, by which the vapourised air ascends to the burner.

Safety-Lamp.—The necessity for artificial light in mining operations below the surface, where the air is frequently impregnated with combustible gases to an extent which renders the mixture explosive when brought into direct contact with flame, has turned the attention of scientific men and mining engineers to the construction of lamps which may, with certain precautions, be safely introduced into an explosive atmosphere. These lamps are called *Safety-Lamps*, and before entering upon a description of their construction, it may be well, from the great interest attached to the subject as connected with our extensive coal mines, to give some account of the gases to be guarded against, and of the circumstances under which they occur.

The evolution of inflammable gases at the surface of the earth has long been known to exist near the Caspian Sea, where they accompany the naphtha springs, and on the Schagday, at a height of 7834 feet. The Holy Fires of Baku are fed by a gaseous mixture containing fire-damp, with 6 per cent of nitrogen, and from 1 to 5 per cent of carbonic acid. Carburetted hydrogen is also found at Pietramala in Tuscany, at Klein-Saros in Siebenburgen, and in several other localities. It also enters into the composition of the gases which escape from various celebrated springs; as, for example, in the—

Hot spring of Aachen, to the extent of	.26—1.82	per cent.
Sulphur spring of Neundorf . .	.17—1.46	„
Mineral spring of Niederlangenau .	8.02	„
Hercules baths of Orsova . . .	.38—0.88	„
Mineral waters of Harrogate . .	.15—5.84	cub. inches per gallon.

On the hill-side near Kangea, North-western India, Mrs. Colin McKenzie, in her work on "Life in the Mission," &c., says many streams of gas have been ignited, the principal of which are enclosed in a temple by the Hindoos, who look on them with great veneration.

The same gas is frequently met with in salt-mines, where it was first noticed by Guettard and Marcel de Serres. Bremer also describes an inflammable gas which escaped from a fissure in the bed of marl in the salt-mine at Szlatina in Hungary, and which was employed to light the mine. A similar gas escapes from an old shaft at the salt-mine, Gottesgabe, and it has been noticed at different points near Lake Erie, as at Fredonia, where it is applied to industrial purposes. It constantly accompanies the salt springs at Marietta in Ohio, and is very common in the salt district of Tseu-lieou-tsing, in China, where it is used for the purpose of illumination, and evaporating the liquor of the salt pans. This gas is also the chief constituent of the gaseous mixture which escapes from the remarkable decrepitating salt of Wieliczka, when dissolved in water, first noticed by Dumas, and which, of course, must exist in a very condensed state. Bunsen found it to contain—

Carburetted hydrogen . . .	84.60
Carbonic acid	2.58
Oxygen	2.00
Nitrogen	10.35
	99.53

Bischof found the gas which was discharged from a bore-hole sunk for an artesian well in the Princedom of Schaumberg in Germany, to contain, after the separation of the carbonic acid,—

Carburetted hydrogen . . .	79.10
Olefiant gas	16.11
Nitrogen	4.79
	100.00

Light carburetted hydrogen is, however, chiefly found in coal-mines, though its existence in brown coal workings has not yet been satisfactorily proved.

The explosions which sometimes occur in these mines, and which are generally attended with such fatal consequences, are caused by the introduction of a naked flame, employed for illumination, or a vivid spark of red-hot metal in a mixture of this with other gases and common air. An explosion, however, only follows the introduction of a vivid spark of red-hot metal when olefiant gas is present, as Mr. Clarke mentions having seen the picks of the workmen strike fire in an inflammable mixture without causing an explosion. This circumstance speaks for the correctness

of the analyses of the gases from the English mines which are given in the following table, and which show no olefiant gas.

The mixture of gases evolved from coal, known in England under the term *Fire-damp,* and in France called *Grisou,* has been repeatedly analysed. The gas from different localities exhibits a general uniformity in composition, consisting principally of light carburetted hydrogen, with varying quantities of carbonic acid, nitrogen, hydrogen, atmospheric air, and sometimes olefiant gas and sulphuretted hydrogen. The following analyses have been published by different chemists :—

TABLE OF ANALYSES OF FIRE-DAMP.

Colliery or Pit.	Seam or Source of Gas.	Spec. Grav. Observed.	Spec. Grav. Calculated.	Light Carburetted Hydrogen.	Air.	Nitrogen.	Oxygen.	Carbonic Acid.	Hydrogen.	Olefiant Gas.	Authority or Analyst.
Wallsend	Bensham	.6024	.5991	91.00	9.00	....	....	....	....	....	Turner.
Ditto	Ditto	....	....	77.50	....	21.10	....	1.30	....	....	Playfair.
Ditto	Pipe above ground	....	....	92.80	....	6.90	0.60	0.30	....	....	Ditto.
Hebburn	24 feet below Bensham..	....	....	91.80	....	6.70	0.90	0.70	....	....	Ditto.
Ditto	Ditto (a month after) ..	....	....	92.70	....	6.40	....	0.90	....	....	Ditto.
Ditto	Bensham	....	....	86.50	....	11.90	....	1.60	....	....	Ditto.
Ditto	Ditto	.6327	....	....	....	....	0.60	....	....	....	Graham.
Jarrow	Ditto	.6381	.6410	81.50	18.50	....	....	....	....	....	Turner.
Ditto	Ditto	....	....	83.10	....	14.20	0.40	2.10	....	....	Playfair.
Ditto	Five-quarter	....	....	93.40	....	4.90	....	1.70	....	....	Ditto.
Ditto	Low Main.....	....	....	79.70	....	12.30	3.00	....	3.00	....	Ditto.
Ditto	Ditto, 11 fathoms lower.	.6209	.6079	89.00	11.00	....	....	....	....	....	Turner.
Burraton	Yard Coal.....	.6060	.5903	91.00	9.00	....	....	....	....	....	Ditto.
Killingworth .	High Main	.6196	.6236	85.00	8.00	7.00	....	....	....	....	Ditto.
Ditto	Low Main.....	.8226	.8325	37.00	46.50	16.50	....	....	....	....	Ditto.
Ditto	.....	.6306	....	82.50	....	16.50	1.00	....	....	....	Graham.
Ditto	.....	....	....	66.30	23.35	6.32	....	4.03	....	....	Richardson.
Hetton	Main, 100 fathoms.....	.7800	.7724	50.00	23.00	27.00	....	....	....	....	Turner.
Ditto	Hutton, 175 ditto	.7470	.7677	50.00	6.00	44.00	....	....	....	....	Ditto.
Pensher	Hutton Waste, 125 ditto	.9660	.9662	7.00	82.00	11.00	....	....	....	....	Ditto.
Townley	Three-quarter Seam....	....	....	50.17	33.15	4.68	....	6.00	....	....	Richardson.
Well-Gate....	Five-quarter	....	.....	98.20	....	1.30	....	0.50	....	....	Playfair.
Gateshead....	Ditto	.5802	....	94.20	....	4.50	1.30	....	....	....	Graham.
Cwm-Twrch..	.....	...	....	19.30	....	63.80	15.50	0.80	....	....	Playfair.
Wellesweiler .	.....	....	....	87.43	....	2 22	....	4 30	....	6.05	Bischof.
Gerhardt	.....	....	....	79.84	....	14.36	....	3.90	....	1.90	Ditto.

The presence of oxygen in some of these mixtures has evidently arisen from the difficulty of collecting the gas in a state of purity. The proportion of nitrogen in many of the samples exceeding that existing in atmospheric air, supports the opinion of Mr. T. J. Taylor and others,—that fire-damp is not *now* spontaneously generated by or in the coal, which is confirmed by the extremely variable

proportions in which the gas issues locally. Mr. Clarke has also noticed, that as the depth increases, and the pressure of the superincumbent strata becomes greater, the gas is more free from carbonic acid, and more inflammable, while the quantity of water given off diminishes and in some cases disappears, but when present, generally contains a quantity of salt in solution. Bischof indirectly confirms this conclusion, as the result of modern investigations shows that the nitrogen is the product of the decomposition of organic matter under circumstances which do not exist in coal-mines.

The constituents of these gaseous mixtures, when compared with the known composition of wood and coal, enable us to form a very probable conjecture respecting the mode of their formation. It is admitted that coal is the product of the gradual decomposition of wood by a kind of mouldering process, in the presence of water, pressure, and a very limited supply of air. These agencies have all had a share in the transformation, but we are unable to trace the influence which each may have separately exerted towards the ultimate result.

If we deduct from the elements of wood .	.	$C_{36} H_{22} O_{22}$
3 eq. of carburetted hydrogen .	$C_3 H_6$	
3 „ water . . .	$H_3 O_3$	
9 „ carbonic acid . .	$C_9 O_{18}$	$= C_{12} H_9 O_{21}$
we obtain the elements of the splint coal .	.	$C_{24} H_{13} O$

of Newcastle, according to the analyses of Richardson and Regnault, while the gaseous products are those which constantly occur in connection with coal. The carbonic acid frequently abounds in the old workings, and being absorbed by water gives rise to the acidulous springs so abundant in the coal measures. The small proportion of nitrogen contained in fire-damp has resulted from that naturally existing in wood separated during the mouldering process. The olefiant and hydrogen gases which sometimes occur must be explained in some other manner, but in reference to the former, it has been remarked that the coking coal from Garesfield, near Newcastle, contains the elements of Cannel coal, *minus* the constituents of olefiant gas, while the formation of the celebrated coal of Boghead illustrates the same point: thus—

Elements of wood	. . . . .	$C_{36} H_{22} O_{22}$
9 eq. of olefiant gas	.	$C_8 H_8$
10 „ carbonic acid	.	$C_{10} O_{20}$
1 „ water	. .	$H O$ = $C_{18} H_9 O_{21}$
leaving the elements of Boghead coal		$C_{18} H_{13} O$

Henry explains the formation of fire-damp by the action of water upon carbon in the following manner:—

$$4\,C + 4\,HO = 2\,CO_2 + 2\,CH_2.$$

It is not, however, consistent with the composition of fire-damp, as found by the above chemists, and a high temperature during the formation of coal would probably have given rise to carbonic oxide, a gas which has not been detected in any of the samples analysed; while the fact that a similar mixture of gases is observed to rise from the mud of stagnant pools where organic matter is in a state of eremacausis, speaks strongly in favour of the mouldering process.

The large volume of gas which issues from coal in some localities with immense force, in the form of *blowers*, and the great pressure to which the carburetted hydrogen must be submitted, renders it likely that it may be partly in the liquid form. Naphtha, which consists principally of liquid hydrocarbon, is known to exude in considerable quantities from some of the coal-formations, a spring of this description being only lately exhausted at Riddings, in Derbyshire. The natural petroleum springs in Persia, France, on the Rhine, and in other places, appear to owe their origin to the same source. Some coal, according to Reichenbach, is impregnated with hydrocarbonaceous oils, which may be separated from it by distillation with water. A heat greatly below redness is sufficient to separate carbon and hydrogen, not only in the form of gas, but liquid, as naphtha, as in Young's processes. Most varieties of coal yield this product, but those possessing the character of Boghead are already employed for the artificial production of oils possessing high lubricating properties.

Mr. Clarke considers that these *blowers* depend upon the locality; for instance, in "fiery seams," where *faults* are found running in the direction of the "facings," or the cleavage of the coal-bed—thus forming, as it were, a natural barrier against the exit of the gas—many of the greatest discharges of fire-damp recorded in the north of England have occurred. He has also found,

in driving across the facings or cleavage of the coal, that more gas was liberated, as it were *draining the seam* on each side, in the same way as if the seam had been loaded with water.

The gases are evolved from all the minute fissures of the coal, generally in a slow and imperceptible manner, but at other times with a distinct hissing sound, as of a confined gas escaping through small apertures from a vessel in which it has been enclosed. This is more frequently noticed when the newly-exposed surface of the coal is moistened with water. The gas sometimes exists in such abundance, and of such great tension, more especially in the neighbourhood of faults or dislocations of the strata, that it will dislodge masses of coal, several tons in weight, with great violence, and, mixing with the air, fill the passages of the mine for a considerable distance with an explosive mixture. It is the occurrence of these bags or reservoirs of gas in the workings, which renders the mining operations in the deeper coal-beds so dangerous. They are seldom met with in working the upper strata, as the gases find more easy vent through the pores of the superincumbent rocks, and often make their way to the surface through natural channels. Discharges of gas of this kind have been observed in many localities, often at considerable distances from the coal measures. One was described by Thomson as occurring at Bedlay, near Glasgow, which consisted of 87.5 parts of fire-damp and 12.5 parts air, which continued to burn for five weeks after it was ignited. At Wallsend Colliery, near Newcastle, as much as 95 cubic feet of gas per minute was evolved from the workings, which, being conveyed in pipes, was used for years in lighting the village, and for a short period at the neighbouring railway station.

In all these cases the gases have a similar origin, but being confined in the deep coal-seams without any natural outlet, they accumulate to such an extent as to acquire very great tension, if not actually to assume the liquid form. The chief ingredient of these mixtures, light carburetted hydrogen, however, has hitherto defied the most powerful artificial liquefying agencies, while olefiant gas has only yielded to a pressure of 27 atmospheres at 0° F., and hydrogen and nitrogen have never been liquefied.

The manner in which these dangerous accumulations of gas sometimes occur is well illustrated and explained by the following letter, comprising drawings and descriptions, of Mr. Clarke, the viewer of Wallsend Colliery:—

Walker Colliery, near Newcastle-on-Tyne,
December 13, 1845.

"The 'high main coal-seam' is here found at the depth of 100 fathoms from the surface, nearly all of which has been wrought out by different shafts, and the 'low main coal-seam' (which is very partially worked) at 160 fathoms, or 60 fathoms below the previous seam. It is about six feet in height, with two thin bands or layers of 'flue metal' running through it."

The air descends by the *Jane Pit shaft* into both seams, and the *Ann Pit shaft* is the upcast from both. There is a furnace constantly burning in the high main seam at this shaft, by which the ventilation in that seam is carried on; the heated column of air in the same shaft also causes a sufficient draught to ventilate the low main seam, as shown in Fig. 302.

FIG. 302.

n Jane Pit. *o* Ann Pit. *p* Furnace. *r* High Main Coal Seam.
s Low Main Coal Seam.

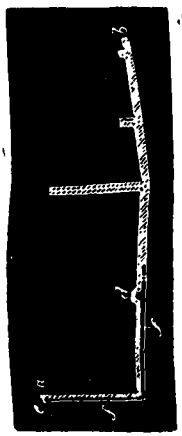
"I shall now give some particulars of two very considerable discharges or eruptions of gas which have taken place in the low main seam near the Jane Pit shaft.

"The first was encountered on November 13th last, when approaching a 'slip-dyke' or fault, marked *a* in Figs. 303 and 304, from the 'back or slip' of which it displaced a mass of coal about 8 feet long on one side, 4 feet on the other, and nearly 6 feet high, weighing, with the disintegrated or 'danty' coal which had wasted from the slip of the dyke, about 11 tons.

"On the displacement of this block, and the discharge of fire-damp

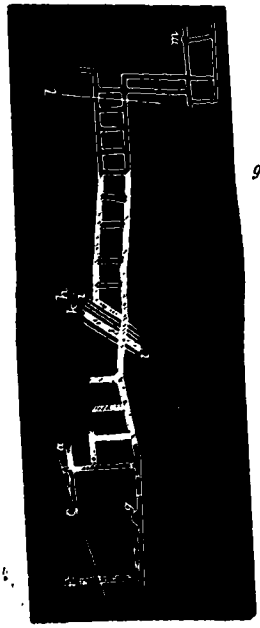
which succeeded, being observed by the two men working in the drift, they immediately secured their lamps, one of which had been partially covered with the fall of coal, but continued to burn, while

FIG. 303.



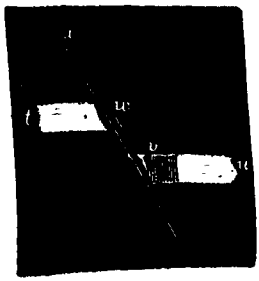
d Jane Pit shaft.
e Upcast to west of 10 feet.
ff This line in centre of the drift represents the wood brattice to carry the currents into the face of each place.

FIG. 304.



g Jane Pit.
h Whin Dyke.
i i Coal partially coked.
k Whin Stone.
l Upcast south of 14 feet.

FIG. 305.



t u Low Main Coal Seam.
v Block of coal displaced, together with
w "Danty" Coal.
x Upcast to west of 10 feet.

N.B. The arrows in all cases show the direction of the currents of air.

the other nearest the current of gas had been put out. They then drew down the wick of the remaining lighted lamp, and hastened to apprise the other men in the pit, extinguishing all the lamps as they proceeded, after which they retired to the shaft, according to the printed regulations appended.

"From observations made at the different places where men were

working, the area of drifts or passages fouled at the same moment amounted to 41,681 cubic feet. The point marked *b* was the most distant place north, in the return air channel, where there was any person at work in the mine, although it is extremely probable that the drift would be fouled beyond this spot. After the lapse of from fifteen to twenty minutes, there were no traces of fire-damp.

"The quantity of air circulating in this part of the mine was 10,483 cubic feet per minute, the current passing at the rate of 6.24 feet per second, or 4¼ miles per hour. The area of that portion of the drift in which this current was confined was about 28 feet."

"The second violent discharge of gas took place on December 10th. Before proceeding further, I may notice the precautionary measures that were taken in again approaching this *slip-dyke*. A *bore-hole* was kept constantly in the coal in advance of the face of the *board* (*a*) to prevent the recurrence of such a discharge, and when the last bore-hole had reached the 'slip' of the dyke and the face of the working, within three yards of it, another bore-hole was put in to touch the seam on the rise or west side of the dyke where it penetrated the coal. No discharge of gas issued from it, and the dyke was fearlessly approached, the coal on the east side being taken away to the slip, and a portion hewn out on the rise, or opposite side of the dyke. The position of the seam being thus ascertained, a portion of the roof was removed to carry up the tramways. While this was being done, the 'danty' or disintegrated coal in the slip of the dyke, above the point where the bore-hole has passed through it, was violently forced out with a noise resembling the exhausting of an immense high-pressure steam-engine, which continued some time, and a discharge of gas followed which filled the workings or passages to a distance of 641 yards in length, or an area of about 86,306 cubic feet. At a distance of about 400 yards from the point of discharge, one of the deputies, who had been with some of the workmen conveying materials from the Ann Pit shaft, met the foulness, and on discovering his lamp to be filled with flame, he drew down the wick. The gas continued to burn in the inside of the gauze for about ten minutes, by which time it was red hot, when the current of air having ceased to be explosive, the flame was extinguished. This lamp shows indications of having been exposed to strong heat, the

particles of coal-dust attached to the outside being burnt red. At a distance of 641 yards, the foulness was met by four men, who, on discovering their lamps to be on fire, immersed them in a *sump* or pool of water near at hand. It will be seen from the sketch, Fig. 303, that the same dyke had been nearly reached at the spot marked *c* when this eruption took place.

"The velocity of the air, and the time that the gas continued to discharge, renders it highly probable that the drift in the direction of the Ann Pit would be foul for a considerable distance beyond the point observed. The quantity of air circulating in the passages at the time was about 16,000 cubic feet, with a velocity in the principal channels of 3.55 miles per hour, and in some of the others considerably quicker. In from twelve to fifteen minutes from its first issue, all traces of the fire-damp had disappeared, excepting to within a yard of the point of discharge, where it mixed with the air, and was carried off. At the blower, the temperature was considerably higher than in the other parts of the mine, which ranged a day or two before at 61°, while at the surface it was 32°.

"It need only be stated that happily no unprotected light had been allowed to be used in the workings of this seam from the commencement.

"These facts prove that in the best state of our present known mode of ventilation, the working of the fiery seam is not safe without the use of protected lights, and assists in explaining how some of the many great explosions in this and other neighbourhoods may have been occasioned, when they could not be attributed to a deficient supply of air.

"On both of these occasions the barometer stood at 30.5."

The pressure of the atmosphere has some influence upon the rapidity with which the gases exude from the fissures of the coal, and accidents have been attributed at times to a very low state of the barometer; but Mr. Taylor has shown, in his paper on this subject in the "Transactions of the Northern Mining Institute," that depressions of the barometer have no settled connection with explosions, and Mr. Clarke, who made a series of observations, extending over some months, on the evolution of gas in mines connected with the indication of the barometer, arrived at the same conclusion,—that the barometer was not a certain indicator of the discharge of fire-damp. In some pits, however, where candles are

generally employed, safety-lamps are lighted when the barometer falls to 29.5 inches, and the candles are extinguished. In others, the men retire when the mercury is observed as low as 29.5 inches. When the barometer falls to 29 inches, the gas hisses in some localities in escaping from the fissures of the coal, while, upon a sudden rise to 30 inches, a similar sound is occasioned by a return of the air through the pores and crevices. The maximum tension of the gas confined by water in a limited space of the mine, was estimated by one of the leading engineers of the north, Mr. T. J. Taylor, in an experiment made in the Bensham seam, at Percy Main, at $4\frac{1}{6}$ atmospheres; but it required some time to attain this elastic force. A pressure of $4\frac{1}{6}$ atmospheres would fully account for the forcible disruptions which accumulations of gas sometimes produce; but the difficulty still remains of conceiving in what condition the gas can be distributed through the entire coal formation. Dr. Hope threw out the idea that the gas might be in a solid condition in the coal, ready to assume the æriform state from a change of temperature, pressure, or other unknown cause.

The specific gravities of the various gases entering into the mixture called fire-damp, are as follows:—

Air	1.0000
Light carburetted hydrogen	0.5596
Hydrogen	0.0692
Olefiant gas	0.9784
Sulphuretted hydrogen	1.1912
Carbonic acid	1.5290
Nitrogen	0.9713
Oxygen	1.1056

In the mines the law of diffusion does not in all cases come into practical operation, and the lighter gases are found occupying the upper portion of the galleries and workings, while the carbonic acid may be noticed creeping along the surface as the gases leave the goaf of some pits.

Of these gases the hydrogen is the most inflammable; when mixed with two or three times its volume of air, it ignites at a temperature just below visible redness, and the flame thus produced will at once ignite the less inflammable gases when mixed in certain proportions with air. It has, however, been rarely detected in fire-damp. Olefiant gas, discovered by Bischof in the mines of Belgium, is also very inflammable, being ignited at a low red heat. It requires 15 volumes of air for complete combustion,

and containing 2 volumes of carbon vapour to 2 volumes of hydrogen condensed into 1 volume, produces twice its own volume of carbonic acid, leaving 12 volumes of nitrogen to mix with the *after* or *choke-damp*. This gas has not been generally found in the mines of this country. Sulphuretted hydrogen is also very inflammable, and is itself a poisonous gas: it seldom occurs in appreciable quantities in the mines of Great Britain, although the pyrites from which it is derived abounds in some districts of the coal fields. Light carburetted hydrogen, which constitutes by far the largest ingredient of fire-damp, is not nearly so inflammable as the other combustible gases. It requires about ten times its volume of air for complete combustion, and containing 4 volumes of carbon vapour to 8 volumes of hydrogen, condensed into 4 volumes, produces its own volume of carbonic acid, leaving 8 volumes of nitrogen from the air. Ignition is only produced in this mixture by a white heat, but is instantaneous in contact with flame. The former fact, in connection with the cooling effect of wire gauze, led Davy to the discovery of the lamp which forms the subject of this notice.

These gases then, particularly the last, ever issuing from the fissures of the coal, and mixing with the air of the mine, constitute the formidable enemy with which the miner has constantly to contend. Light being requisite to enable him to carry on his operations, he is reduced to the necessity of either diluting the gases with air to such an extent as will render them inexplosive in the presence of flame, or so securing the source of light as to prevent it communicating sufficient heat to the combustible mixture to cause it to explode. The latter alternative has, in many cases since the time of Davy, been too confidently relied on as sufficient safety, while the equally important precaution of ventilation has been neglected in too many of the collieries. It is not to be understood that the Davy itself is to blame, for we have the experience of Mr. T. L. Taylor, during forty years in the north of England, to prove that no authenticated instance has occurred of explosion from the use of unimpaired Davy lamps.

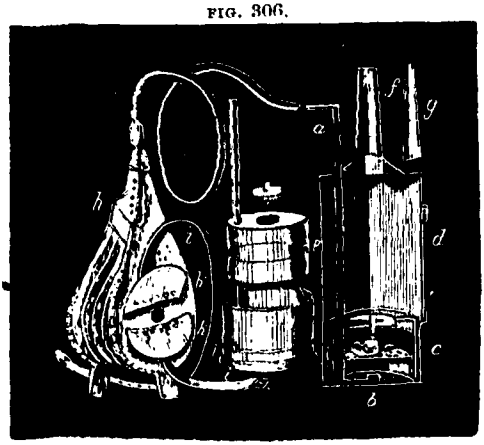
The demands of the miner for greater security in his perilous occupation, and the self-interest of the owner for protection to his property, are daily calling attention to the subject of mine ventilation and illumination, while engineers of the highest standing,—Wood, Forster, and Taylor,—are engaged in testing the respective merits of the furnace and steam-jet as ventilating powers.

Upon this latter question it is not our province to enter, and we confine ourselves to the consideration of the various methods proposed for obtaining light in a mine exposed to an explosive atmosphere.

Candles or open lamps are employed in mines not subject to the evolution of these combustible gases in dangerous quantities, and in those parts of a mine where the supply of air is so great as to reduce the mixture below the explosive point, but it is very doubtful whether any system of ventilation will be so perfect as to provide against sudden evolution of fire-damp, which rarely or ever takes place at the ordinary atmospheric tension. Mr. Speading introduced the use of the *steel-mill*, which was the first step towards mining in an explosive mixture, but the lamentable loss of life which still continued soon attracted the attention of men of science and practical experience to the investigation of the problem, how to render human life secure, under such conditions, by the combined means of improved ventilation and safety-lamps.

Humboldt was the first to suggest in 1796 the use of a safety-lamp instead of the *steel-mill;* but his lamp was very inconvenient, and not very safe. In 1813, Dr. Clanny, who was unwearied in his exertions in this cause, invented a lamp which burnt safely in a fiery atmosphere, and of which we give a drawing, more for the sake of illustrating the progress of investigation in this branch of applied science than for any present practical utility it possesses. The accompanying woodcut is a section of the lamp: *a* represents the pipe into which the flexible tube of the bellows is fitted. The air is forced down this pipe, and rises at *b* through the oil; *c* is a plate, or false bottom, perforated with holes, which supports the cotton and preserves the oil from the action of the flame; *d* a curved pane of glass; *e* the plate round the burner full of holes, through which the air is supplied; *f* the chimney, with

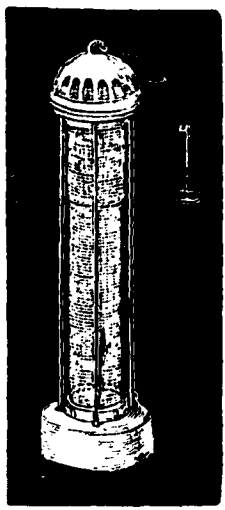
FIG. 306.



an additional piece *g*. The bellows *h*, with the straps *i i*, and cushions *k k*, are shown at work in the woodcut. The lower vessel is made air-tight with leather.

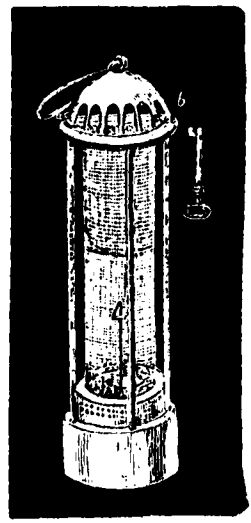
This lamp was superseded in 1815 by that form which has rendered the name of Davy so illustrious, and entitled him to the gratitude of mankind. While we assign this honour to Davy, we have great pleasure in adding that our equally distinguished countryman, George Stephenson, had made the same discovery perfectly independent of the chemist, and the "Davy" and "Geordey" both live to attest the fame of these eminent men.

FIG. 307.



Davy.

FIG. 308.



Geordey.

Davy found that of the following mixtures brought into contact with a lighted taper,

1	vol. of inflammable gas	with	2	vols. of air,	burnt without exploding.
1	,,	,,	8	,,	ditto.
1	,,	,,	4	,,	ditto.
1	,,	,,	6	,,	inflamed with a slight whistling sound.
1	,,	,,	7	,,	ditto, rather a louder noise.
1	,,	,,	8	,,	ditto, the greatest noise.
1	,,	,,	9 to 14	,,	ditto, a diminished sound.
1	,,	,,	15	,,	the flame enlarged without exploding.
1	,,	,,	16 to 30	,,	the increase of the flame gradually diminishing.

Thus the most explosive mixture consists of 1 of gas with 8 of

air, although, as we have already stated, there ought to be, according to theory, 10 of air for perfect combustion.

Davy also found that carburetted hydrogen is so much less inflammable than carbonic oxide, olefiant gas, hydrogen, &c., that a charcoal fire may be blown up to whiteness by an explosive mixture of this gas and air without producing any explosion. Hence no *incandescent* or *red hot* body will explode such a mixture, provided there is no flame.

Carburetted hydrogen requiring so high a temperature for combustion, it has been found that this extreme heat cannot be maintained, while the gaseous products pass through metal tubes of a certain diameter (first noticed by Tennant, in his "Researches on Flame") or gauze wire, of a certain fineness, which Davy described as a *section of tubes*, the excess of heat being dissipated by radiation and conduction.

Another remarkable fact has been observed, that some gases, in certain proportions, prevent the ignition of explosive compounds: thus Davy found that a mixture of 2 parts of hydrogen and 1 of oxygen did not explode when mixed in the proportion of,

1	part with	8	parts of	hydrogen,	while explosion took place with	6	parts.
1	„	9		oxygen	„ „	7	„
1	„	11		nitrous oxide	„ „	10	„
1	„	1		carburetted hydrogen	„ „	$0\frac{3}{4}$	„
1	„	2		sulphuretted hydrogen	„ „	$1\frac{1}{2}$	„
1	„	$0\frac{1}{2}$		olefiant gas	„ „	$0\frac{1}{3}$	„
1	„	2		muriatic acid gas	„ „	$1\frac{1}{2}$	„
1	„	$0\frac{5}{9}$		fluosilicic acid gas	„ „	—	„
1	„	—		hydrofluoric acid gas	„ „	$0\frac{3}{4}$	„

If, therefore, we suppose an inflammable gaseous mixture in a state of combustion, to be enveloped by a metallic gauze of sufficient fineness, the heat will be dissipated by the metal, so as to reduce the temperature of the gases as they pass off, below the point of ignition.

Such are the principles upon which the construction of the safety-lamp depend, and we may now describe the "Davy" itself, with the various modifications which have been suggested or adopted.

Fig. 309 is a front view; Fig. 310, a section; Figs. 311 and 312 are horizontal sections, according to M N and M′N′; Figs. 313 and 314 show the details.

The lamp will be seen to consist of three distinct parts, viz., the lower portion or base, forming a reservoir for oil; the body, or circular

envelope of wire gauze impermeable to the flame; and the exterior brass framework. The oil cistern A A is a cylindrical metal box, the upper surface of which is formed of a copper or brass plate with a cir-

FIG. 309.

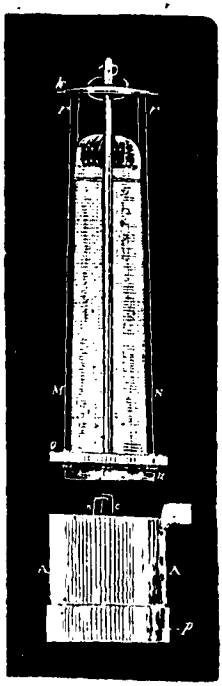
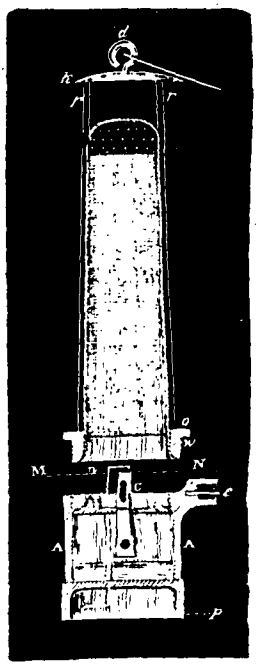


FIG. 310.



Davy.

FIG. 311.

FIG. 312.

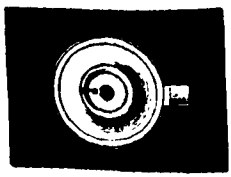


FIG. 313.

FIG. 314.

Davy.

cular opening in the centre. A ring screws into this opening, rising slightly above the surface, Fig. 314. The socket which supports the wick, Fig. 313, consists of a circular plate *a b*, attached to a vertical tube *c*. This tube has a lateral rectangular opening *g*, through which the hook *n* is made to adjust the wick. This hook

accurately fits the tube which passes through the oil cistern, which has a slight projection *p* to receive the handle of the hook to prevent the wick receiving any injury from suddenly forcing the hook upwards by placing the lamp incautiously on the floor.

The chimney or cylinder is formed of gauze wire, containing from 700 to 1000 meshes to the square inch, and is about 6 inches long with 1¼ inch diameter. A greater diameter, by enclosing a larger body of inflammable gas in a state of combustion, would sooner heat the gauze red hot, and destroy its texture.

The frame is composed of four or five strong metal rods *r r* attached to an upper plate of metal *k*, which protects the lamp from water dropping from the roof of the mine, and to a circular ring *o* at the bottom, fitted with a screw *w* for insertion in the oil cistern.

A ring *d* is attached to the plate *k*, by which the lamp can be held by the hand or suspended from the roof.

The cylinder is further secured to the oil cistern by the lock *e*. Various contrivances have been proposed by Regnier and others to render this more secure, and one very generally adopted is shown in Figs. 307 and 308, registered by Mr. Watson. It consists of an ordinary lock, but requires a long key to pass across the top of the lamp *a b*.

The upper portion of the lamp was formerly made of a double sheet of gauze wire, which was soon corroded and destroyed by constant contact with the aqueous vapour formed during the combustion at such a high temperature as the interior of the lamp acquires. This objection has been obviated in some localities by employing perforated sheet copper, although in all carefully conducted mines the men are never allowed to continue their work when such circumstances arise.

Davy also proposed to employ a coil of fine platina wire round the flame, so that, in the event of its being extinguished, there might still exist sufficient illumination for the miner; but this has failed in practice.

This form of lamp has naturally, and very properly, been the subject of innumerable experiments and reports in this country and on the continent, from which the following conclusions have been drawn:—

1. That a metallic gauze envelope of the usual description is perfectly safe for an indefinite period, in mixtures of varying proportions of carburetted hydrogen and atmospheric air, so long as

the atmosphere is tranquil, and no other more combustible gases are introduced.

2. That the metallic gauze of a good lamp will resist the action of the flame for about twenty minutes: in some cases for less, but in none for a longer period. The combustion of the gas in the interior rapidly destroys the gauze after this period.

3. That the condition of the interior of the cylinder always indicates the state of the surrounding atmosphere, as to the proportion of inflammable gas it contains. Thus a slight increase in the volume and length of the flame attests the first appearance of gas. The cylinder becomes filled with a light bluish flame as soon as the gas increases to between 8 and 9 per cent of the mixture. When the proportion reaches 16 to 20 per cent, the flame of the wick disappears, being absorbed by that filling the cylinder, and is extinguished when the percentage amounts to one-third.

4. The Liége Commission have proved that when the lamp is exposed to a current of pure hydrogen gas, the explosions which ensue pass through the gauze after a few seconds; and that when the hydrogen is mixed with 25 or 50 per cent of common coal gas, the explosions are very brilliant and numerous, but they are confined to the interior of the cylinder. (See vol. i. p. 309, of the Ann. des Travaux Publics de Belgique.)

5. The same commission have proved that the formation of small holes, of .12 to .19 inch diameter, by the destruction of the gauze, will not permit the gas to pass outwards, provided they are 2 to 3 inches above the wick. An opening of .08 inch diameter, however, on a level with the wick, allows the explosion to pass, especially if its direction is towards the bottom of the lamp.

6. That, according to Bischof, the safety of a lamp diminishes as the diameter of the cylinder increases. (See Erdmann's Journ. für Pr. Ch. B. 14.)

7. That, according to Erdmenger, if the lamp is plunged in a mixture barely inflammable, the wire gauze becomes red hot, while it remains unchanged in an explosive mixture. (Karsten's Archiv, v. 208.)

8. That Davy himself found a stream of air or gas will drive the flame through the gauze; and Gurney has shown that a current with a speed of 300 feet per minute is sufficient. (Parliamentary Report, Quest. 9.)

9. That the illuminating power of the Davy is much inferior to

that of a pit candle and some other lamps, as the following determinations by Messrs. T. J. Taylor, Parish, Clark, and Easton, show:—

Standard, a wax candle of 6 to the lb.	Average No. of lamps required to equal wax candle standard.
Davy lamp, with gauze	8.00
Stephenson's lamp	18.50
Upton and Roberts'	24.50
Dr. Clanny's (glass)	4.25
Mueseler's (glass)	3.50
Greener's (talk)	3.50
Parish's lamp, with gauze	2.75
Davy's lamp, without gauze	2.50
Common pit candle (30 to the lb.)	2.00

10. That the original cost is moderate, and the repairs both cheaply and easily executed. The weight is small, and not so fatiguing as other lamps. In travelling "wastes," often through narrow passages and in the most awkward posture, no one can realise the full force of the objection to a heavy lamp without having carried one in the hand for several hours. The following table, partly taken from the Shields Report, shows the difference in this respect:—

	lb.	oz.
Davy	1	6
Mueseler	2	11
Clanny's improved	2	6
Upton and Roberts	2	0¼
Stephenson's improved	2	3½
Elsin	1	4
Glover and Cails	2	4

In this resumé all the objections to the Davy lamp have been candidly stated; but it must be noticed here, as the concurrent testimony of all mining engineers, that at its first introduction it was exposed to much more severe tests than any to which it is now submitted. The practice was to work with it when the gauze was in a *red hot state*, in which condition it is known to have remained for hours. This is no longer permitted, the rule being for the miner to retire as soon as his lamp indicates the presence of gas. This fact apparently militates against the second conclusion, which, however, alludes more to the possibility of danger, than to its actual existence.

The great argument in favour of the Davy is that of *experience.* It may be estimated that from 12,000 to 15,000 safety-lamps are now in daily use in Durham and Northumberland, nine-tenths of which are Davy lamps. This, of course, exceeds the yearly average in use since the invention of the lamp; but there is no doubt that, as a mean, several thousands have been employed. If we multiply this number by the time elapsed, and take into consideration, at the same time, that no authenticated accident has happened from the use of this lamp, we are justified in stating that a very high degree of security has been reached.

The question hence arises, how far this security depends upon its structure, which combines strength and simplicity with sufficient illuminating power, and freedom from the use of any brittle material?

As a partial answer to this query, we propose to describe the various modifications which have been suggested to meet the above objections, while they seek to retain the acknowledged advantages of the "Davy."

Stephenson invented his lamp, and satisfactorily proved it in 1815 in Killingworth Colliery, the principle being to admit the air by a chimney with a tube at the bottom. It consists of a wire gauze cylinder, about 2¼ inches in diameter and 5½ to 6 inches high, with a glass shield inside. The air for combustion is supplied through a triple circle of small perforations in the metal bottom, protected from external injury by the oil vessel which is screwed over them, leaving, however, a passage for the air. A metal chimney, full of small holes, is fixed inside on the top of the glass cylinder. When the glass is destroyed, this lamp is not so safe as the Davy, as the diameter, 2¼ inches, is too large for an explosive mixture. The late Mr. Smith, of Newcastle, improved this lamp by passing the air through the wire gauze as well as through some perforations placed on the under side of a rim near the bottom, where they are free from exposure to dust and oil. The rim forms a hollow chamber open to the interior, over which the gauze of the cylinder is stretched, thus affording the security of perforations and gauze, at right angles with each other, against the passing of the flame. This modification of Stephenson's lamp is extensively used in the north of England.

In the lamp invented by Upton and Roberts, Figs. 315, 316, 317, we have an illustration of an arrangement for obviating the danger arising from a current of air. The cylinder consists of wire gauze,

about 5½ inches long and 1½ inch in diameter, and is attached to the reservoir in the usual manner. The lower half is protected by a thick glass cylinder, and the remaining portion by one of copper, screwed to the upper ring of the frame. The glass is firmly compressed between the cylinder and the cistern, so as to prevent all communication between the interior and exterior. The air necessary for the combustion enters through a range of small openings in the upper part of the cistern into a space protected by a double shield of closely-compressed wire-gauze, through which it must pass before it reaches the wick. The cone retains these shields in their positions, and forces the air upon the wick, where it is found in practice to be entirely consumed.

FIG. 315.

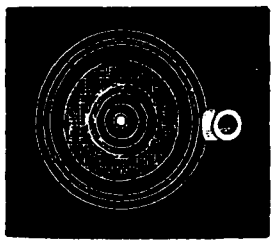


FIG. 316.

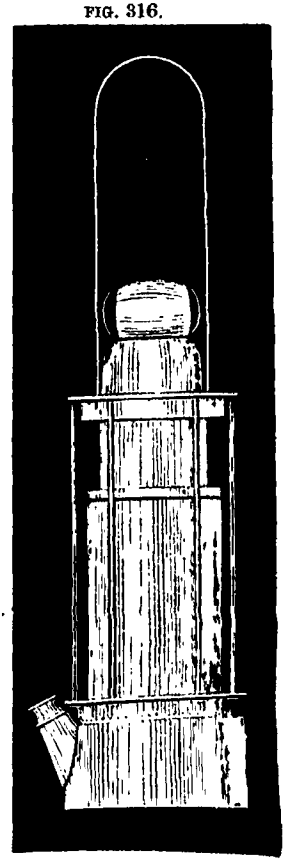
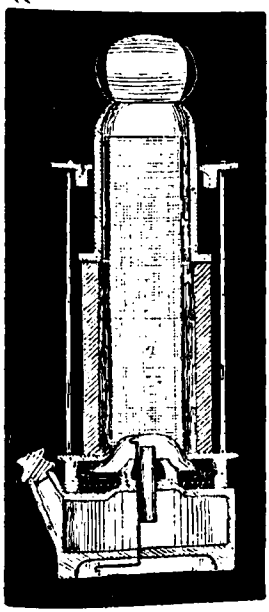


FIG. 317.

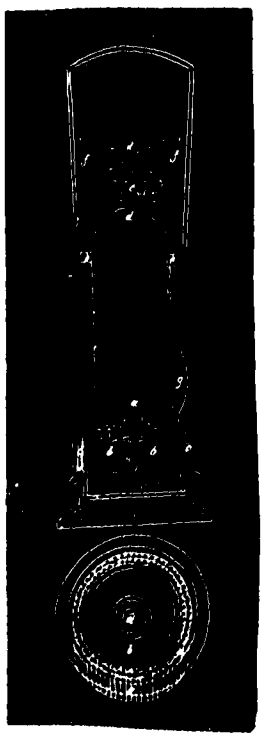


This modification resists the action of any current of hydrogen which can be directed against it, and is perfectly safe in any inflammable mixture, as the explosions cannot be propagated beyond the interior. The difficulty which the atmospheric air finds in entering, prevents too rapid a combustion of the oil or of the gaseous compound, and the over-heating of the metallic gauze. Any accident to the gauze still leaves a safe lamp, as the glass cylinder remains; and should the latter be broken, the lamp becomes an ordinary Davy.

The objections urged against this lamp are its high price, the brittle nature of the glass cylinder, the liability of the double gauze to become foul from dust or the waste of oil from the cistern and wick, and the certainty of its being extinguished by continued explosions in the interior. Its illuminating power is very low, and some of the following lamps originated in a desire to remedy this defect.

Mr. Martin's lamp, Fig. 318, is even more delicate than Upton and Roberts', as the flame is immediately extinguished when introduced into an explosive mixture without either explosion or the ignition of the gas within the lamp. It consists of the usual oil cistern, with a glass cylinder 4½ inches long and 2 inches diameter, and a copper chimney, gradually contracting till it assumes a conical shape. The air is admitted, as in Stephenson's lamp, through holes in an upper metal plate, forming part of the wick-holder. The excessive delicacy and unprotected glass cylinder are grave objections to this form.

FIG. 318.



This lamp, improved by John Martin, is represented in the accompanying woodcut. *a* is the wick, *b* the oil cistern, *c* grooved cylinders for the passage of the air, *d* copper top, *e* the break, *f* exit for the products of combustion, *g* glass lens, *h* the universal joint to suspend the lamp.

Dumesnil has also attempted to overcome the double difficulty of increasing

the illuminating power, and protecting the flame against a rapid current of air.

FIG. 319.

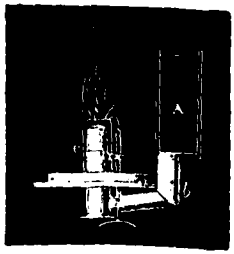


FIG. 320.

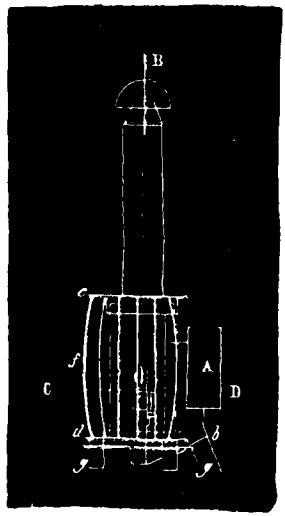


FIG. 321.

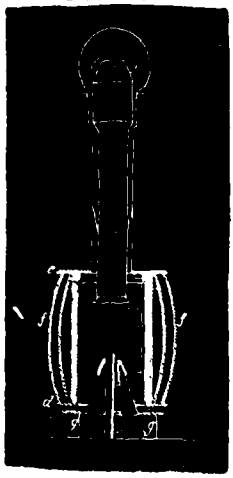


FIG. 322.

The reservoir A of his lamp, shewn in Fig. 319, 320, 321, and 322, is of a rectangular shape, and attached to one of the sides of the lamp, in a vertical position. The wick is flat, and the oil is supplied through a pipe *b* at a level above that of the lower metal plate *d*. Two tubes *c c*, slightly inclined towards the side of the wick, supply the air necessary for combustion. The opening is closed by wire gauze. The glass shield is carefully annealed for this special object, and is secured between the two metal plates *d e*. It is protected from blows by curved iron bars *f f*. The lamp is supported by four feet *g g*. The chimney of sheet metal is contracted towards the top, where the products of combustion escape. A double envelope, towards the lower end, projects into the body of the lamp to give steadiness to the flame.

The lamp is as safe as Upton and Roberts' when the air-tubes

are covered with wire gauze. When a large quantity of gas is present, a peculiar noise is heard, or, as the inventor expresses it, *Elle crie dans le danger.* It diffuses an excellent light, at least equal to that from three Davys, consuming a little more oil, and burning eight to ten hours without requiring attention.

The great objection to this lamp arises from the circumstance that the glass cylinder is the only protection, which is liable to be broken by a fall of the lamp itself, by pieces of rock, by an accidental blow from the workmen's tools, or a sudden external cooling while the glass is hot. It would appear, from experiments made at Anzin, that in some cases, even when a jet of water was projected on the hot glass so as to cause a fracture, the pieces of glass retained their position; but Noeggerath found, at the mines at Saarbrucken, that either the glass flew into scattered fragments, or the lamp sustained serious injury. The free opening at the top apparently presents a source of danger, especially during the falling of the coal; but it is probable that the gas already burnt would extinguish the flame as it fell back upon the wick. The coal-dust is also very apt to choke the air-tubes, especially as it is necessary to employ very dense gauze. The sudden overflow of the oil sometimes extinguishes the light, though this might be prevented by adopting M. Lorieux's suggestion of employing very small tubes for the oil. The weight and bulk of this instrument prevent it being used as a portable lamp.

In describing the last modification which Dr. Clanny made in his safety-lamp, we are glad to be able to avail ourselves of the South Shields Report, which is so valuable a compendium of information on every point connected with "accidents in coal mines." They first quote Dr. Clanny's own paper: "The diffusion of heat through gases is effected in a great measure by the motion of their particles amongst each other. We are indebted to Dr. Priestley, Dalton, and Professor Graham, for much valuable information in respect to the diffusion of gases; and from the valuable experiments of the last-named philosopher we are assured that the same quantity of different gases escapes in times which are exceedingly unequal, but have a relation to the specific gravity of the gas. The light gases diffuse most rapidly; thus hydrogen escapes five times quicker than carbonic acid, which is twenty-two times heavier than that gas. In the case of an intimate mixture of two gases, the most diffusive gas separates from the other, and leaves the receiver in the greatest proportion. Volatile bodies rise

into the atmospheric air as well as into a vacuum, and obviously according to the law by which gases diffuse through each other. Heat is conducted by air in the same manner that it is conducted by water and other fluids, namely, at low temperatures by communication only, and at high temperatures by the effect of the diminution which the weight of heated particles or molecules undergoes, and by the motion in ascent thereby imparted. It is a law deduced from the physical properties of gaseous bodies, that the velocities of gases, flowing under like circumstances into a vacuum, is inversely as the square roots of their densities, which is precisely the same law that regulates their flow into each other. Holding these facts in view, I constructed my new safety-lamp, and by experiment I found that just within the glass, and opposite the flame, the temperature was 108° on Fahrenheit's scale, and between the top of the rim and of the wire gauze cylinder the thermometer indicated 302° of temperature. I need scarcely remark, that in all lamps the air is constantly changing, and that in this safety-lamp *the operation of the high temperature causes the expansion and diffusion of fire-damp, or of any other inflammable gas which may surround it; whilst, at the same time, a very small quantity of inflammable gas will find its way to the flame of the oil lamp, but will be diffused into the atmosphere.*"

The new lamp was constructed with an impervious metal shield, having glass and lenses in its sides, only open at the highest part of the gauze cylinder for about 1½ inches from the top, and surrounding the lamp entirely to the oil vessels, the shield being in diameter fully half an inch more than the lamp. There is, consequently, no admission or egress of air, but *only over the top of the shield* at the highest part of the lamp. The light from this lamp was too small for practical purposes, which Dr. Clanny obviated by placing a thick globular shield of glass opposite the flame, which is found to reflect the light in a very perfect manner, the air being exclusively supplied from above. The committee add: "At first sight, it appears singular that the entire of the interior within the shield should not be filled with nitrogen, carbonic acid gas, &c., and the light thereby extinguished, which invariably takes place when an external shield is made of so small a diameter as closely to envelope the gauze cylinder. It is thus demonstrated that in a lamp of this construction, the air for the supply of the flame passes down between the cylinder and shield, and returns up the interior of the middle of the lamp, and is thrown off at its highest part on

the principle laid down by Dr. Clanny; and the air, having to descend through a heated medium, excludes much of the light explosive gases, both from their specific gravity and their increased diffusibility, from the operation of heat. This they conclude may, in some measure, account for the steadiness and brightness with which, in a moderately inflammable atmosphere, as well as in a current, this lamp continues to burn."

Dr. Clanny's lamp is, on the whole, superior to the Mueseler lamp, to which it has some similarity, but which it preceded in point of time by at least twelve months.

Mueseler's lamp, Figs. 323, 324, 325, and 326, is a combination of those of Davy and Dumesnil. The cistern, the opening for the wick, and its adjusting rod, are the same as those of Davy. The glass shield, fitted with tin plate at each end, occupies about two-fifths of the entire height, and is fixed in the ordinary manner, the lower edge resting in an annular recess on the upper surface of the cistern. A conical tube of sheet metal forms the chimney, and carries off the products of combustion, while it isolates the air which feeds the flame. The frame is composed of two sets of bars, the lower eight being intended to protect the glass, and the upper four, inclined towards the top, support the gauze cylinder. The total height is about 10 inches, and its external diameter about 3½ inches. The flame is entirely protected from all communication with the exterior, except through the wire gauze which covers the top of the glass cylinder.

This lamp is as convenient as that of Davy, but does not diffuse as much light as that of Dumesnil. It resists the action of a current of air or gas, and there is no danger of the sudden extinction of the flame from the choking of the tubes or gauze by the oil. The gauze is not so readily obstructed by coal-dust as is the case with the Davy, and does not require so much cleaning. It is perfectly safe, for when plunged into an explosive mixture of air and hydrogen, even without the protection of its metallic cylinder, the explosion does not pass outwards. When this lamp is brought into an explosive mixture, the flame is lengthened and then extinguished. This arises from the circumstance that the air supporting the combustion descends from above, while the carbonic acid collecting at the bottom of the cylinder gradually rises to a level with the wick, and extinguishes the flame. This exquisite sensibility is considered an objection by some engineers; but it would really be an invaluable property, did not an inclination of the lamp on one side produce the same effect. A strong ascending

current of air acts on the flame in the same manner, as has been noticed at Mons. This happens so often that a number of

FIG. 323.

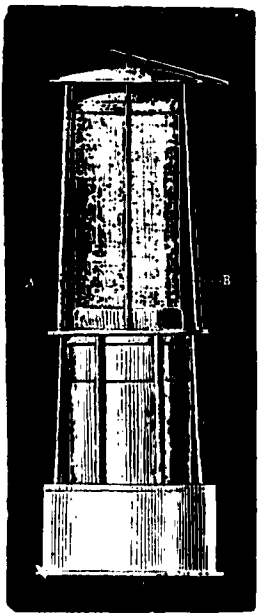


FIG. 324.

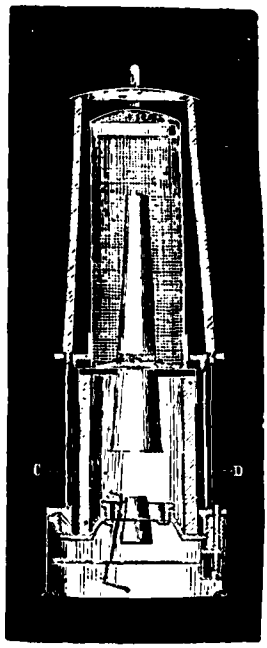


FIG. 325.

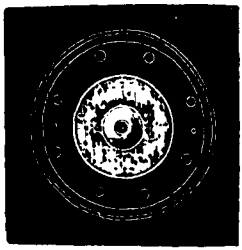
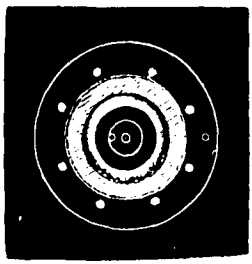


FIG. 326.

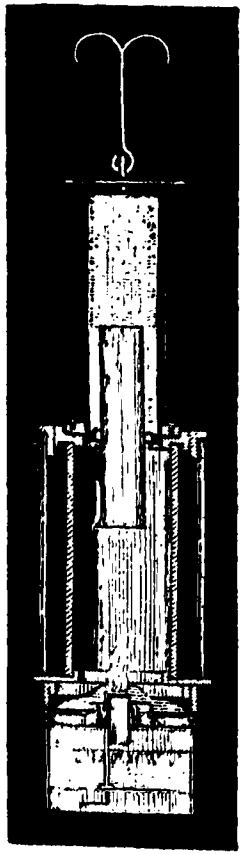


boys are employed in the mines of Liège to rekindle the lamps extinguished from this cause.

The shadow produced by the intermediate ring of the cylinder, and the necessity of keeping the chimney so near the wick, confines the zone of light within very narrow limits, which is a great drawback in large workings. The comparatively unprotected large glass cylinder is a more serious objection; but Mr. P. S. Reid considers it a safe lamp, and states that 12,000 are in daily use in Belgium.

Combes has attempted to combine the advantages of the preceding lamps. The cistern, Fig. 327, similar to that of Davy, is surrounded by a cylindrical rim, which is pierced with a series of holes intended to admit the air, and covered with two layers of wire gauze. The air, in passing through, reaches a metal plate with a circular opening, which concentrates the whole of the air near the flame. The framework is formed of six rods, connected by two rings.

FIG. 327.



The glass shield rests upon the lower one, with an intermediate piece of cloth or leather. The upper part of the lamp is composed of a trellis, protected by six iron rods, and at the bottom a shield of wire gauze supports a copper tube or chimney in its centre, which promotes the ventilation and increases the draught of air through the cistern. The products of combustion escape through the meshes of this shield, and as they cannot accumulate between the chimney and the glass cylinder, there is no danger of the flame being extinguished by any movement of the lamp or by any current, however rapid. The glass is sometimes slightly blackened by smoke at its upper end. There is also some danger of the meshes of the gauze being obstructed by an overflow of oil from the cistern, which would also cause the lamp to smoke.

Boty's lamp, Figs. 328 and 329, resembles Upton and Roberts's, but the glass cylinder has no wire gauze. A ring of copper is fixed to the upper surface of the cistern, pierced with a number of holes, and so arranged that the upper part corresponds with the base of the flame. A glass cylinder rests upon it, and is surmounted by a cylinder or shield of wire gauze. This lamp is safe in ordinary mixtures, but a current of hydrogen carries the explosion through the gauze after it has become red hot.

The openings in the ring are not of much value, as the lamp continues to burn after they are closed, though it has been found

at Charleroi that the men have attempted to enlarge them for the purpose of increasing the light.

FIG. 328.

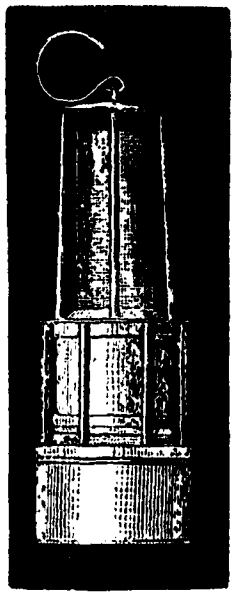
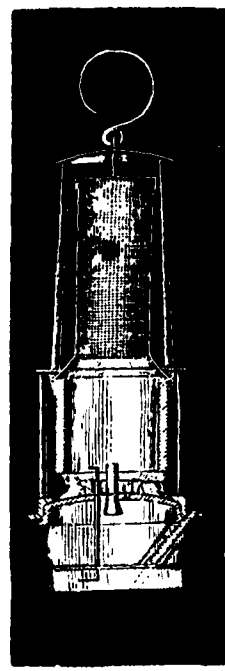


FIG. 329.



The lamp of Mons. Eloin, Figs. 330 and 331, next demands our attention. A cylinder is fixed between the upper surface of the cistern and the glass shield, pierced with six rectangular holes, and covered with wire gauze, through which the air enters upon the wick, where it is entirely consumed by means of a cone similar to that of Upton and Roberts. The glass shield has a concave outer surface, so as to disperse the light. A copper chimney is connected with the base, the upper end of which is pierced with numerous small holes, to allow the gaseous products of combustion to escape. A copper reflector slides upon the bars of the frame, which may be placed above or below the flame, so as to throw the light upon the roof or floor of the mine.

MM. Hemptume and Stas have reported favourably of this lamp, and found that a considerable quantity of the gas which enters the lamp escapes unconsumed. The copper chimney is a

great improvement over the wire gauze, as it is not so liable to injury, and effectually prevents the introduction of any gas through the sides. The gas only partially inflames in the interior, and cannot burn after the extinction of the wick. The lamp is shorter

FIG. 330.

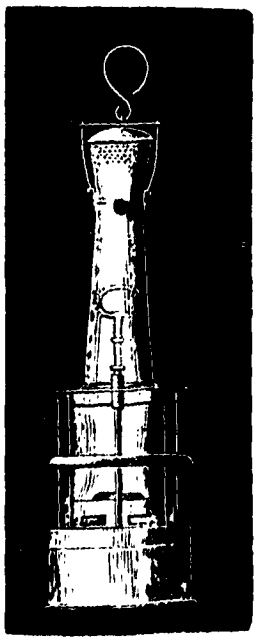
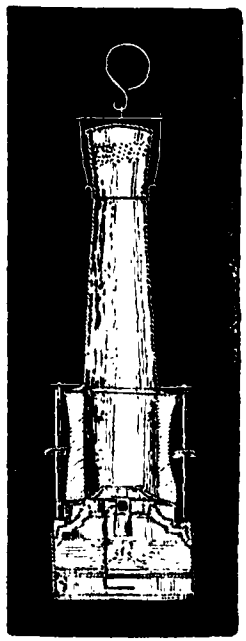


FIG. 331.



than usual, and weighs little more than $1\frac{1}{4}$ oz. It, however, smokes more readily than the lamps already described, and the flame is apt to be extinguished by a descending current of air. It also becomes so hot that it is often necessary to attach wooden handles. As ordinarily manufactured, it is too fragile for the rough work of a coal mine.

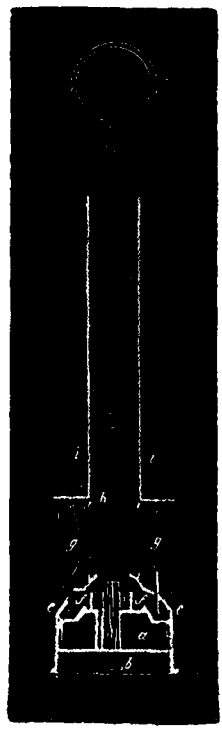
Mr. Parish has proposed a lamp somewhat similar to the preceding. In Figs. 332, 333, and 334, *a* represents the oil cistern, with a bent wire *b* to snuff the wick through the wick tube *c*. The air to support the combustion is admitted through the perforated plate *e*, when it meets a cylinder of wire gauze *f*, and lastly, a cone of the same material. Another cylinder of wire gauze *g* protects a strong glass shield of the internal form shown in the woodcut, or it may have a convex form, as represented by the dotted lines. A chimney *h* passes up through *i* made of wire gauze and slightly conical. The products

of combustion pass off through a gauze disc at the top. The inventor electro plates the gauze over the glass with silver, in order to increase the light. He also proposes to employ talc, crystal, or any other transparent material, in place of glass.

FIG. 332.

FIG. 333.

FIG. 334.



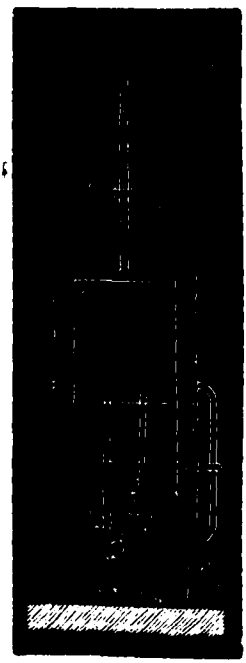
The employment of talc has been suggested by Dr. Fyfe and Mr. Hewitson, in their "Improved Clanny," which presents great similarity to the original, having the gauze chimney or cylinder in the upper part and the glass shield surrounding the flame. Immediately above the oil vessel, and below the wick, is a series of lateral perforations, with a floor of single gauze above. In this way a constant ascending supply of air is admitted from below, which materially assists the ascent and escape of the heated products of combustion. The glass cylinder, which is the great objection to the Clanny and similar lamps, is protected by an outer cylinder of talc, without, it is said, seriously reducing the

illuminating power. This shield of talc has been found an effectual protection against the sudden application of cold air or water. The gauze cylinder has a double top.

Where the upper part of the glass cylinder meets the metal frame, there is a rim of vulcanised caoutchouc, which compensates the unequal expansion of the glass and metal.

While Dr. Fyfe's object was thus to preserve the benefit of greater light, by protecting the glass, it occurred to Dr. Robinson to obviate the danger of the flame of an explosive mixture passing through the gauze, by means of a delicate valve opening upwards, to guard the aperture through which the air enters.

FIG. 335.



In the event of any explosion or sudden expansion of the gases within the lamp, this valve is pressed down, and thus cuts off all communication with the air at the most dangerous point. Dr. Robinson received the thanks of the Society of Arts for this modification of the safety-lamp, of which the annexed woodcut, Fig. 335, is a section, showing the position of the valve.

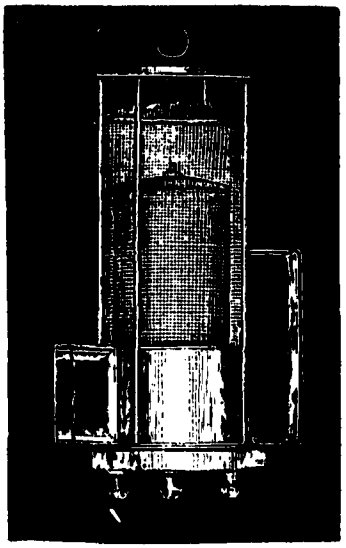
Dr. Clanny proposed to accomplish the same object by means of an extinguisher, to which he gave the name of "shield lamp." The extinguisher consisted of three brass tubes or shields, which acted like the tubes of a telescope, and when drawn out nearly covered the lamp. This shield was maintained in its place by a delicate brass wire, which melted as soon as a flame reached it, as in the case of an inflammable atmosphere filling the interior of the lamp. The support being destroyed, the shield descended, protecting the flame, and only emitting sufficient light to enable the miner to escape. This contrivance, however, does not protect the flame from the action of a current, which might drive it through the gauze without ever coming in contact with the support.

Mr. Ayle has also constructed a lamp with the same object, and employs similar means to Dr. Robinson. His "barometer lamp" contains a valve through which the air passes, but which falls as soon as the atmosphere becomes light by the admixture of carbu-

retted hydrogen. He has also constructed another lamp, in which there is a contrivance to extinguish the flame as soon as any attempt is made to unscrew it, as lately suggested by Simons.

We are indebted to the Mining Journal for the following description of Simon's lamp, Fig. 336, which is formed of an oil vessel in the usual manner, having a concave metallic reflector at the back of the wick. The front is an air-tight door made of talc or thick glass, secured in a metal frame. This is surmounted by a cylinder of wire gauze, which is made double with an annular space between as additional security, especially in fiery mines. In addition to a fixed handle and ring for suspension, it is connected by a pivot, on which it may be made to revolve, and by which it can be attached to the walls of the workings, while the reflected light may be thrown in any direction.

FIG. 336.



In a lamp proposed by Bonner, Figs. 337 to 339, to increase the illumination, by employing several small wicks *a a* round a central tube *b*, which are trimmed by the wire *c*, there is a peculiar contrivance to extinguish the light, so as to avoid the danger of blowing upon the wick. This is done by bringing a large volume of cold air suddenly upon the flame so as to reduce the temperature below that necessary for combustion.

This contrivance consisted of two covers *d d*, which extinguished the flame while unscrewing the gauze envelope, which is enlarged at *f f* to afford space for these covers. They are made of thin sheet metal, placed on the upper side of the lamp, moving on the pivot *o o*, and carried over the light by one or more catches on the screw ring, as shown at *e*. He also employed an extinguisher *g*, formed of a thick circular piece of metal of nearly the same diameter as the gauze cylinder. It was made with two grooves to slide on two wires *h h*, to guide its ascent and descent. The extinguisher was suspended by any combustible body, which, when

consumed, allowed it to press upon the driver *i*, and to fall upon the light. It might be supported by a pin *k*, inserted at *m* or *n*.

FIG. 337.

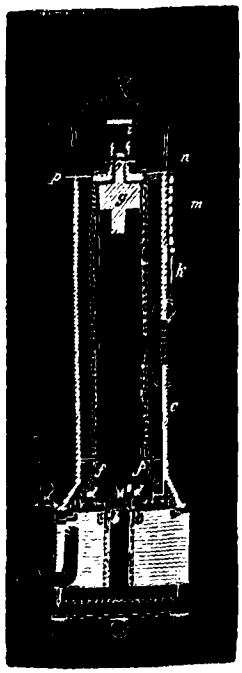


FIG. 338.

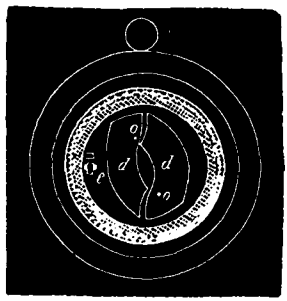
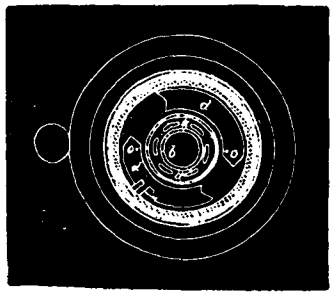


FIG. 339.



At a meeting of the Society of Arts, Mr. Roberts states that he has constructed a lamp with a double cylinder of glass, the space between being filled with water. When either cylinder is broken, the water acts upon a trigger inside, which, by means of an extinguisher, puts out the light.

One of the most recent attempts to promote the cause of humanity in this direction has been made by Dr. Glover and Mr. Cail, who employ a double glass casing, Figs. 340 to 343, with a current of air between, in order to keep the cylinder cool, and thus remove the great objection to the use of this material. The superior light of such lamps doubtless removes one cause of danger, by enabling the miner to dispense with the use of candles where lamps ought to be employed. This arrangement has this further advantage, that when the outer cylinder is broken by contact with cold water or a current of cold air, the inner one remains intact.

a a is the oil cistern for supplying the wick, which is inserted in the conical tube *b*. The wick is adjusted by the bent wire *c*, which passes through the bottom of the lamp. The cistern is attached to the bottom ring *d d* by means of a screw *e*. The upper ring *f f* is connected with the lower one by the vertical pins or standards *g g*.

FIG. 340.

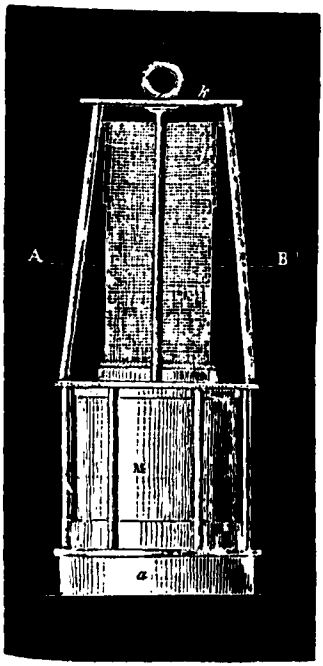


FIG. 341.

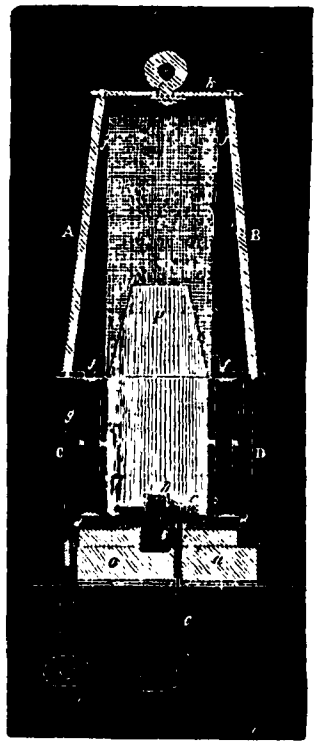


FIG. 342.

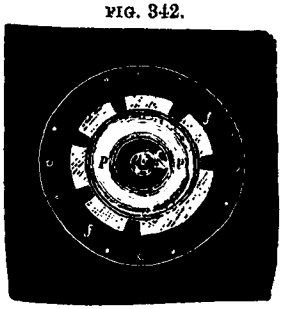
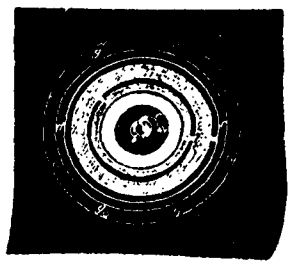


FIG. 343.

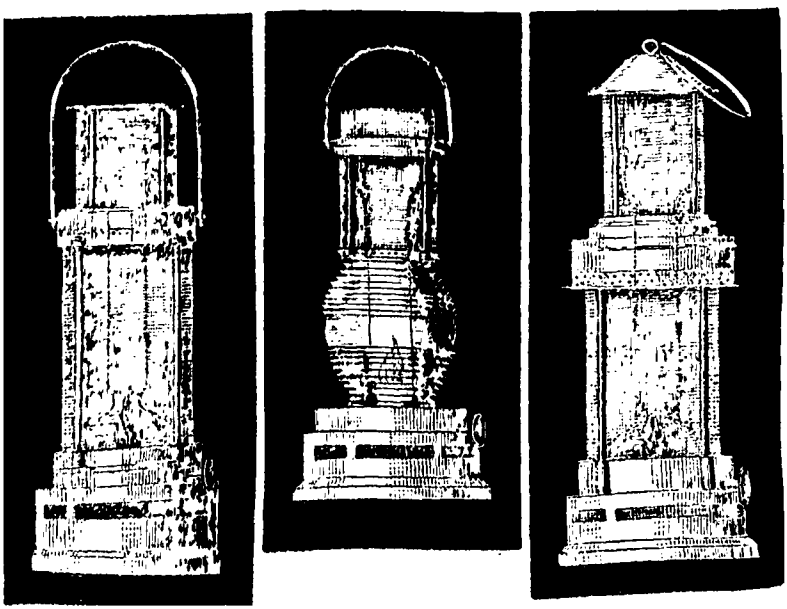


An ordinary wire-gauze chimney *i i*, with a movable cover *j*, is attached to the upper ring, and the lamp can be carried or suspended by a handle or chain through the ring *k* at the top. The air supporting combustion passes the holes made in the upper ring *f*, and after passing through the meshes of a ring of wire gauze *i*, it descends through the annular passage formed between the two glass cylinders *m* and *n*. These cylinders are supported from below, and rest upon a second ring of wire gauze, which lies upon the projecting pieces *o o o* of the lower ring *d*. The passage of the air from the outside between the glass cylinders effectually accomplishes the object of the inventors. A small conical tube *p p*, is placed inside the gauze chamber, a little above the flame, which promotes a steady draught and prevents any flickering of the light.

This lamp indicates the presence of gas with great delicacy, which will not burn in the upper part, the lamp being self-extinguishing.

The last modification of the safety-lamp which we have to notice is the invention of Mr. T. Y. Hall, a detailed description of which will be found in the Transactions of the Northern Mining Institute. A cylinder of glass, Figs. 344 to 346, within the wire gauze rests upon

FIG. 344. FIG. 345. FIG. 346.



the dome of the air vault, and closely surrounds the central aperture of the wick, by which means a current of air is concentrated about the flame, and greater intensity of light obtained. The air for feeding the flame is introduced through perforations in the dome of the air vault at about four inches from the bottom, and the cylinder of gauze below these apertures may be protected from dust by a double cylinder of glass. The air descending between the inner cylinder of glass and the inner chimney tends to keep the lamp cool, and any accidental fracture of the glass is not attended with danger so long as the gauze remains uninjured. The upper part of the lamp is constructed of double or triple gauze, or gauze lined with perforated copper. An Argand or solar burner may be used in this lamp, and the encasing cylinder of glass protects the flame from the action of any sudden burst or rush of gas. The gauze employed in these lamps has 1296 meshes per square inch, or about double that in ordinary use. Mr. Hall has since suggested heating the oil in a cistern supported by the lower standards, which are hollow. This excellent suggestion will save oil and produce a more brilliant flame, without the same risk of smoking. The danger of over-heating, in cases where the interior of the lamp fills with flame, may be avoided by employing a double case for the cistern, which would protect the oil from any excessive heat. Mr. Wood's experiments at Killingworth show that this is a valuable form of lamp.

Davy, in his memoir, says he tried the electric light without success; but it has been revived by Mr. Stagg, who suggested the use of the electricity of the waste steam of the colliery boilers by means of Armstrong's machine. He proposed to carry the wire down the shaft, breaking contact where a light was required. The two points were to be enclosed within a double glass cylinder, hermetically sealed, somewhat similar to that now used by Glover, Cail, and Roberts. The addition of a reflector would increase the illuminating power.

There are practical difficulties in the way of the general adoption of this plan, but in some localities it might be advantageously employed for fixed lights.

Finally, Professor Graham has suggested the use of bleaching powder, scattered over the floor of the mine, to absorb the carburetted hydrogen as it is evolved. The cost of this plan prevents its adoption.

In resuming, we confess to a feeling of satisfaction on surveying

the amount of patient investigation and ingenious effort which has been brought to bear on this subject for nearly half a century. For ourselves, we believe the Davy, in the hands of a steady intelligent workman, attending to the necessary precautions, to be a trustworthy instrument. The cooling current of air proposed by Dr. Glover and Mr. Cail, and Mr. Hall's hot oil cistern, are improvements in the right direction, while the addition of an interior chimney would increase the efficiency of the Davy. Some contrivance, somewhat similar to that employed in Beale's lamp, may possibly be suggested, to dispense with the present cotton wick and its necessary dressing, which produces so much smoke and so varying an amount of light. A lamp of an oval form, with the light at one end, a reflector as a shield, and combining the two improvements to which allusion has been made, suggests itself to us, after the perusal of the various publications we have consulted in preparing this section, as a modification likely to be successful.

Such is a brief description of the Davy lamp, and of the modifications suggested by actual experiment for perfecting its construction.

When the Davy was first introduced in the collieries of the North, it was received with rapturous applause; and such was the implicit confidence reposed in the instrument, that numerous accidents resulted from neglect of ordinary precautions, and produced a reaction in the minds of many against the use of a safety-lamp at all.

The safety offered by the Davy consisting in the perfect isolation of the flame by means of a metallic envelope, it is obvious that every precaution is indispensably necessary to prevent any communication being established between the exterior and interior; and this is more necessary in the case of some gases than others, as, for example, when the nitrogen amounts to 44 per cent.

Among such precautions the following may be enumerated:—

1. No lamp ought to be opened *on any pretence,* excepting by a person appointed for the purpose, and in a suitable locality.

2. When accidentally extinguished, it ought to be replaced by a lighted one from another part of the mine.

3. No lamp with the slightest defect ought to be employed, and each lamp ought to be carefully examined daily for this purpose by a competent person.

4. The miners themselves ought to be controlled by moral and technical instruction, as well as the fear of legal punishment in cases of imprudence.

5. The men should carefully protect the lamp against blows or injury from the falling of the roof, or any other cause likely to destroy the cylinder or enlarge the meshes.

6. They should carefully guard against the passage of the flame through the gauze, especially when it has acquired a high temperature,—as in passing through a *trap door*, or any narrow air course, where the current is more than usually rapid.

7. The lamp should not be brought too near the hewn coal, which in the act of falling creates a sudden current or gust of air,—an effect produced by a fall of the lamp itself, by the movement occasioned by quick walking, by attempting to extinguish the flame by blowing upon it from any direction, or by rapidly closing and opening a door.

8. The men ought also to suspend the lamp, while working in that part of the current which is most pure, near an angle or at a certain height above the floor, but never in a confined locality, nor behind the props, where it may happen to meet with foul air, while the other portions of the working are safe, as at Hebburn.

9. The indications of the flame itself, than which it is impossible to have a safer guide, ought always to be followed.

Such or similar instructions ought to be printed, and a copy given to every miner, as is the case with railway guards and drivers. We give a copy of the excellent rules printed for the use of the miners in Walker Colliery:—

INSTRUCTIONS.

"No light, excepting the Davy lamp, to be used beyond the shaft or Davy cabin, on any pretext whatever.

No person to work in any place where indications of fire damp are shown, under any circumstances.

General Instructions.—Any person observing any door standing open that ought to be shut, any stoppings injured, brattice displaced or broken, or any other erections injured, whereby the ventilation of any part of the mine may be deranged or obstructed, such person is immediately to inform the overman, deputy, or other person then in charge of the pit, of the same.

No workman to commence working in any place until it has first been examined by the overman, deputy, or other authorised person.

No hewer to commence or continue working in any place where

he considers the timber, &c. insufficient to support the roof of the mine, nor is he to work in any place whatever where he, himself, considers the place in danger from any ordinary mining casualty, it being distinctly understood that it is the express directions of the viewer that no one shall be compelled, nor even asked, to work in any place under any such circumstances.

No man or boy shall proceed to his employment until the overman, deputy, or other authorised person, shall have properly examined and locked his lamp previous to its being taken from the shaft or "Davy cabin" adjoining; and any person having an imperfect lamp is not to be allowed to pass to his employment until he shall have given a satisfactory reason for any such damage. If found to have been caused by carelessness or neglect, the offender shall not be allowed to resume his work until the case is fully laid before the viewer.

Every person who has the use of a lamp shall take home the gauze thereof for the purpose of its being properly cleaned before it is again used.

The hewers to hang their lamps at such a distance from the face of the place where they are working as to prevent the possibility of their being injured by splinters from the coal, falls from the side of the place, roof, or goaf, or other casualty.

No putter, pony-driver, or helper-up, is, under any pretext whatever, to carry a lamp during his work. A sufficient number will, at all times, be placed on the going roads to afford sufficient light for the performance of their work.

Any workman seeing another using his lamp in any improper manner, is strictly enjoined to inform the overman or other person then in charge of the pit.

All persons are strictly prohibited from interfering in any way with their lamps, further than the necessary trimming of the wick with the picker.

Every workman, the light of whose lamp shall have gone out, must send the lamp out to the "Davy cabin" by the person appointed for that purpose, and before it is again used must be examined by the authorised parties before mentioned.

Any hewer or other workman meeting with any "blower" or sudden discharge of gas, or observing by the usual indications the presence of fire damp, must immediately draw down the wick of his lamp; and should the gas inside of the gauze continue to explode, he must protect it from the current by his clothes or other

means, and hasten to apprize the people working near him, that their lamps may be extinguished, and to retire, if possible, by the intake air course. The overman, or other person then in charge of the pit, to be immediately acquainted with it.

The lives of the workmen and the property of the owners depending upon the strict observance of the foregoing rules and regulations, it is hereby directed, that any person acting contrary to those conditions shall forthwith be turned from his or their employment, fined, or prosecuted at the option of the owners or their viewer: and every one is hereby enjoined to aid and assist in the detection of any or all such offenders.

OFFICERS' DUTIES. *Overmen.*—The overman is to see that the foregoing rules and regulations are fully carried out; to examine every working place in the pit at least once a day; to examine all the principal air currents, stoppings, doors, brattices, and other things connected with the ventilation of the mine; and immediately on hearing of any sudden or other discharge of gas, any falls obstructing the horse or other roads, or air courses, to proceed forthwith to the place, and to adopt such measures as may remedy any such accident or defect.

To see that a sufficient quantity of timber is sent into the workings, and so placed or set as to ensure the safety of the workmen.

To examine daily, and record in a book kept for that purpose, the state of the barometer, and any extraordinary event that may have occurred in the mine.

To report to the viewer, as often as it may be necessary, the general state of the workings, and more particularly if any circumstance should occur to render the mine unsafe from any discharge of gas, falls of the roof, or other casualty.

Back Overmen.—The back overman to have full charge of the pit in the absence of the overman, and in every way to take such measures and precautions as may be necessary for the safety of the workmen and the proper management of the mine.

Not to leave the pit until the whole of the workmen have left it, and to see that all lights are extinguished; afterwards to see the overman, and report to him the proceedings of the day.

Deputies.—The fore-deputies to go down the pit every morning two hours before the men for the purpose of examining the state of the mine, particularly the working places, before the hewers proceed to their work. Each deputy will be held responsible for the setting of the timber and other things necessary for the safety

of the workmen in their respective districts; to report any irregularity in the ventilation that may occur, unfair working of the places by the coal hewers, or any other circumstance that may have happened in their respective districts.

Master Wastemen.—The master wasteman to go down the pit every morning before the hewers; to examine the intake air currents, the return currents, the furnaces, and the quantities passing into every separate district. If any current is found deficient, not to leave the pit until the cause thereof is ascertained, and, if possible, remedied. On knowing any place in the mine to be foul, at once to inform the viewer of the same.

The attention of officers is hereby directed to the "Mining Inspection Act" recently passed,—to its penalties, and the responsibilities laid upon all having any charge in the management of coal mines. And notice is hereby given, that the law will in every case be allowed to take its course; none will be screened from their responsibilities, nor shielded from its penalties.

G. CLARK, Viewer."

Before concluding, we annex some tables which show to what extent the introduction of the safety-lamp has been beneficial, by reducing the loss of life. The following table illustrates this point in the mines of the Loire:—

Years previous to the Use of the Safety Lamp.	Numbers Killed or Wounded.	After the Introduction of the Safety Lamp.	Numbers Killed or Wounded.
1817	18	1825	4
1818	15	1826	17
1819	17	1827	1
1820	21	1828	1
1821	11	1829	33
1822	18	1830	2
1823	19	1831	2
1824	10	—	—
Years 8	119	Years 7	60

Or, the mean annual loss of life in the two periods is respectively 14.87 and 8.57. When the increase of the mining population is considered, the advantages of the Davy lamp appear in a more striking light, as is shown by the following table:—

Periods.	Mean Number of Miners Employed.	Annual Loss of Life.	Relation between the Numbers Employed and the Lives Lost.
1817 to 1825	2079	14.875	1 in 142
1825 to 1831	2928	8.571	1 in 345

Mr. T. J. Taylor's valuable contributions to the Commons' Committee do not at first indicate the same favourable result as respects this country: the following table embraces his statistical returns:—

BEFORE THE INTRODUCTION OF THE DAVY LAMP.

Periods.	Number of Explosions.	Lives Lost.	Lives Lost per Annum.	Lives Lost per Explosion.
1756 to 1765	5	34		
1766 to 1775	6	101		
1776 to 1785	9	41		
1786 to 1795	12	105	12.23	12.03
1796 to 1805	12	151		
1806 to 1815	17	308		
AFTER THE INTRODUCTION OF THE DAVY LAMP.				
1816 to 1825	20	296	32.00	14.88
1826 to 1835	23	344		
AFTER THE PARLIAMENTARY INQUIRY.				
1836 to 1845	15	328	25.64	22.43
1845 to 1849	1	31		

We are, however, indebted to this gentleman for the following information on this subject, which, while it confirms the preceding table in one sense, shows that life is really safer in this country than on the continent. The two tables also present a most striking contrast in favour of recent improvement:—

LOSS OF LIFE IN THE COAL MINES OF DURHAM AND NORTHUMBERLAND, FROM 5 APRIL 1811 TO 31 JULY 1815, BEING A PERIOD OF 4¼ YEARS.

	Persons Employed under ground.	Lives Lost.	Tons of Coal Raised.	One Life Lost for Tons of Coal Raised
Durham.....	2276	122		
Northumberland ...	5840	318		
	8116	440	2,614,648	25,760
		= per annum, 101.5 or 1 in 80		

The above table has been compiled from actual returns in the coal trade office, and embraces the serious loss of life occasioned by the Heaton inundation and the Great Felling explosion. The total number of persons employed in the coal trade of these two counties at this period was,—

Underground . . .	10,081
Aboveground . . .	3,668
	13,749

but the returns of accidents only comprise the numbers given in the previous statement.

LOSS OF LIFE IN COAL MINES IN DURHAM, NORTHUMBERLAND, AND CUMBERLAND, FROM THE COMMENCEMENT OF THE ACT FOR THE INSPECTION OF MINES.

Periods.	Shafts.	Explosions.	Choke Damp.	Falls of Stone and Coals.	Sundries.	Total.
From 30 Nov. 1850 To 30 June 1851 } 8 months	13	8	1	21	29	72
To 31 Dec. 1851—6 do.	5	49	—	15	19	88
To 30 June 1852—6 do.	17	33	1	19	27	97
To 31 Dec. 1852—6 do.	11	5	—	26	16	58
To 30 June 1853—6 do.	12	7	—	28	32	79
To 31 Dec. 1853—6 do.	17	12	1	30	12	72
Totals.....	75	114	3	139	135	466
Average for 6 months	13	18	½	23	23	77½
Average for 1 year	26	36	1	46	46	155
Year ending 1853	29	19	1	58	44	151

Number of persons employed underground estimated at 33000.
Loss of Life, 33000 ÷ 155 = 1 in 215.

In Durham and Northumberland 1 Life is lost for every 84000 Tons of Coal raised.
In Great Britain ..... 1 Life do. 43000 do. do.
In Belgium ..... 1 Life do. 34000 do. do.
At St. Etienne ..... Something more than in Belgium.
In Germany ..... Average rather more than in Belgium.

Mr. Taylor concludes his communication with the following remarks:—"More lives are lost in Great Britain, in proportion to the *number employed* in coal mines, than on the continent, a result which at first sight appears contradictory to the above statement, but which is easily explained. For example: the average output from each pit in Belgium appears to be about 23000 tons, equal to 100 tons per day for 280 working days. In Durham and Northumberland, 400 or 500 tons per day are frequently raised

from one pit. This difference gives rise to a fallacy in the comparison of our results of casualties as compared with those of Belgium. Each pit has a certain establishment upon it, and when the pits are relatively numerous, those establishments increase in a proportional or nearly proportional degree. A number of *small* collieries have thus more workmen *out of harm's way* than a few *large* ones, and if a conclusion is attempted to be drawn from the gross number of persons employed, that conclusion will, for the reason given, be incorrect. In point of fact, the proper and right method of comparison is to ascertain the quantity of coals raised relatively with that of the persons whose lives are lost. This is the only true measure of the *underground risk.*"

SHADES, REFLECTORS, &c.

The complete and uniform combustion of the oil or fuel so as to afford the greatest amount of light, is not the only point requiring attention in a perfect system of illumination; the proper diffusion of the light, with a judicious regard to the nature of the eye, being equally important. A light which is more intense than that of the illuminated objects weakens the impression made upon the eye, and causes them to appear darker and less distinct. The eye is then said to be dazzled by the light,—it can no longer clearly distinguish the objects in the immediate neighbourhood of the flame, while those which are more distant, and less illumined, are seen distinctly, because the impression produced is not weakened by the simultaneous and more powerful action of the flame itself.

Ground-glass, or translucent glass (milk-glass) in the form of hollow globes, half-globes, bell- or vase-shaped vessels, are the common means employed for lessening the dazzling effect of the flame. This subject was incidentally adverted to in speaking of the sinumbra-lamp, where the ground bell-glass plays an important part. The action of these ground-glass shades in diffusing the light is remarkable; the outline of the flame itself becomes no longer visible, while all the rays of light proceed from the surface of the globe or bell, which thus has the appearance of being self-luminous, and as the rays sent from it cross each other in all directions, the objects in the neighbourhood can only throw short, indistinct shadows. Coloured glasses produce a somewhat similar effect, but are little used, in consequence of the unnatural tint which they impart to all surrounding objects.

Light naturally diffuses in all directions, which has led to the introduction of various contrivances to concentrate it on certain points where it is most required. Reflectors are generally used for this purpose; but for lighting rooms, ground-glass shades of different shapes may be employed, which reflect a portion of the rays, and simple tinned or silvered screens, the inner surface of which is polished or whitened, to prevent the absorption of light. When a downward direction must be given to the light, conical shades are generally used, like that shown in Fig. 264. The light is then reflected from the straight sides of the cone, as from a number of flat surfaces. In the case of wall lamps, where all the rays of light should be reflected and carried forward in a horizontal direction, concave tinned screens, or screens made of small pieces of glass mirrors, arranged together so as to approach the form of the parabola, are employed.

Although, for domestic purposes, it might be considered superfluous to devote much attention to the means of refracting and reflecting the illuminating rays, yet there are occasions where human life and property are involved, as in the construction of lights for the guidance of seamen, when it becomes of the utmost importance that no available ray of light from a given source should be allowed to stray uselessly from the direction in which it can be of service; and for the accomplishment of this, the most noble application of artificial light, the resources of abstract science, and the skill of the most accomplished artificers, have been combined. It is not our province to describe in this place the wonderful ingenuity displayed in the construction of our modern lighthouses, nor, indeed, to encroach upon the science of optics further than to give a general idea of the mode in which the laws of that branch of physics have been brought practically to bear upon the construction of the lighthouse lamp, by the united efforts of many engineers, but more particularly of Arago, Fresnel, and our own countrymen, the Stephensons.*

It may be premised that the intensity of the light from ordinary divergent rays diminishes rapidly, in the ratio of the square, with the distance from its source; and whenever the greatest amount of intensity is required in any particular direction, the chief object will be to collect the divergent rays, and transmit them

* For more full particulars upon the subject of lighthouse lamps, we refer to Mr. Stephenson's work, and to an excellent article in Tomlinson's Cyclopædia of Useful Arts, to which we are much indebted.

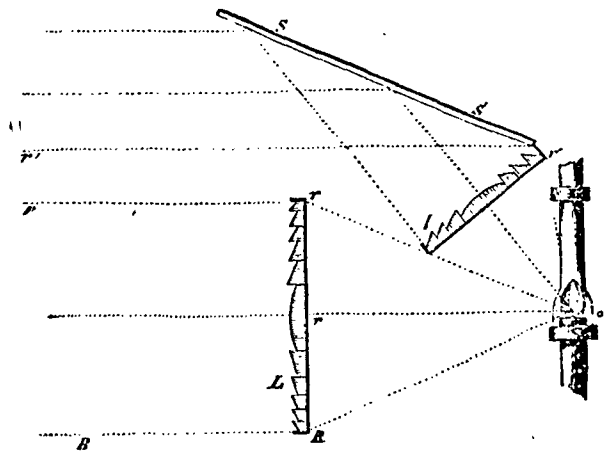
in a parallel direction. Perfect parallelism of the rays can only be produced in two ways,—either by reflection, when the flame or source of light is brought into the focus of a parabolic mirror; or by refraction, when it is placed in the focus of a glass lens.

Reflection is employed in the catoptric lights, which are either fixed or revolving. In the former case, a number of silvered paraboloidal mirrors are arranged round a central frame, each containing an argand lamp in its focus, with a chimney passing through the upper part of the mirrors. In lighthouses of moderate height, the axes of the mirrors are arranged perfectly horizontal, while in those which are more elevated a slight outward inclination is given to the faces of the mirrors, so that the axes produced may be tangents to the earth at the visible horizon of the light-room. Several tiers of reflectors, one above another, are employed in the large lights. The revolving light is produced by attaching larger reflectors to a frame having three or four sides, which is made to revolve by machinery. The appearance produced is that of a gradually increasing light, which as gradually disappears; and by employing coloured glass chimneys to the lamps, or placing discs of coloured glass before the reflectors on the different sides of the flame, differently coloured lights may be made to succeed each other at certain fixed intervals. The colour, however, requires to be strongly marked, and cannot be produced without a considerable loss of intensity, the absorption amounting to from four-sevenths to five-sixths of the whole. The *flashing* light used on the Scotch coast is produced by a different construction of the revolving frame; the reflectors on each of eight sides being arranged with their faces in one vertical plane, and their axes in a line inclined to the perpendicular. This disposition of the mirrors, combined with the greater quickness of the revolution, shows a flash once in five seconds of time, producing a very striking effect, totally different from that of a revolving light, and presenting the appearance of a rapid succession of bright flashes alternately rising and sinking. The *intermittent* light is distinguished by bursting suddenly into view, continuing steady for a short time, when it is suddenly eclipsed for half a minute. Its striking appearance is produced by the perpendicular motion of circular shades in front of the reflectors, by which the light is alternately hid and displayed.

Although the refracting power of lenses was proposed and tried in lighthouses as early as the middle of the last century, the difficulty of

obtaining large lenses sufficiently free from faults, and the still greater difficulty of accurately grinding them, together with the large amount of light absorbed by thick glass, prevented their adoption. After suggestions had been thrown out by Buffon and Sir D. Brewster, Fresnel succeeded in constructing or building up with single polished lens-rings, bound together by a frame, a compound or annular lens, presenting the same surface and producing the same effect as a single piece of glass. Annular lenses of this description, constructed of crown

FIG. 347.



glass, with an index of refraction of 1.51, were first tried by Fresnel and Arago in the year 1822, and applied to the *dioptric* system of lighting in the French lighthouses. The Dutch soon copied the French system, and in 1835 the commissioners of northern lighthouses, at the suggestion of their engineer, Mr. Alan Stephenson, replaced the catoptric arrangement at Inchkieth by a dioptric instrument. The superiority of the dioptric system was there rendered so apparent, that its introduction became general.

As only one lamp is employed in the dioptric lights, and as much light as possible must be evolved in a small space, it is constructed (according to the rank of the lighthouse) of two, three, or four Argand burners, placed one within the other, each having a double draught of air, and supplied with a constant flow of Colza oil, upon Carcel's principle. The wick-holder is separate in each burner by the glass chimney, lengthened by a metal tube, is common to all. Thus constituted, the compound burner is placed in the focus of the system of lenses. In the revolving dioptric lights, mirrors are

employed in conjunction with the lenses, and their relative positions in relation to the burner will be evident from Fig. 347. Two rows, each row comprising eight lenses, surround the burner; one of the lower and larger lenses is shewn at *L*, and one of the smaller inclined lenses at *l*; above both are placed the reflectors *S*. The rays between *R* and *r* are collected by the compound lens *L*; and, as the flame is in the focus *O* of both sets of lenses, *L* and *l*, the rays are refracted, and proceed in the form of two bundles of parallel rays. Thus far, the whole light would be emitted in the form of two cylindrical, or, from the imperfection of the lenses, slightly conical bundles of rays, of which one only would proceed in the direction of the horizon, the other being uselessly directed towards the sky. The direction of the latter rays is changed by the mirrors *SS*, one of which is placed above each smaller lens, so as to reflect the rays in a parallel or slightly downward direction towards the horizon.

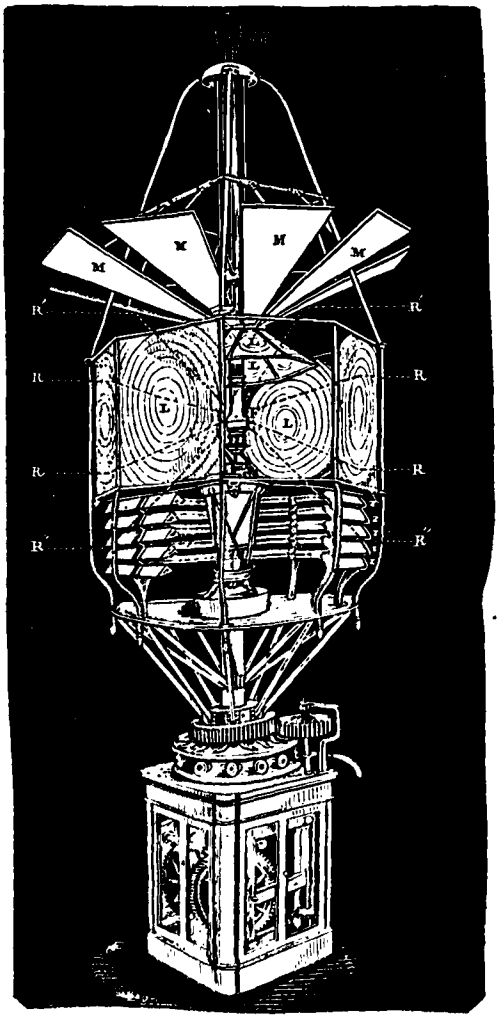
Fig. 348 represents the entire *revolving dioptric* apparatus, with the clock-work machinery for giving it motion. F is the focal point where the lamp is placed, L L are the large annular lenses forming together an octagonal prism, L′ L′ are the upper lenses forming a frustrum of an octagonal pyramid of 50° inclination, and by means of which the rays passing over the lenses L L are rendered parallel, and subsequently reflected in a horizontal direction by the plane mirrors M M; Z Z are the lower zones of totally reflecting prisms, substituted by Mr. Stephenson for curved mirrors, which were at first employed by Fresnel, and over which they have the advantage of being less perishable as regards their polish; these parallelise the rays which fall below the lenses L L.

This light appears to a distant observer in a succession of flashes or blazes of light, whenever one of its faces crosses a line joining his eye and the lamp, the blaze being much more intense, but of shorter duration, than that produced by the mirrors, the latter quality being proportional to the divergence of the resultant beam.

In the large lens employed in lights of the first order, the focal distance of which is 36·22 inches, the central disc is about 11 inches in diameter, and the annular rings which surround it gradually decrease in breadth, as they recede from the axis, from $2\frac{3}{4}$ to $1\frac{1}{4}$ inches, the whole presenting a surface of 1,300 square inches. Mr. Stephenson calculates approximatively the increased power of illumination by the use of the lens as the quotient of the surface of

the lens, divided by the surface of the flame: he says, "The illuminating effect of the great lens, as measured at moderate distances, has generally been taken at 3000 argand flames, the value of the

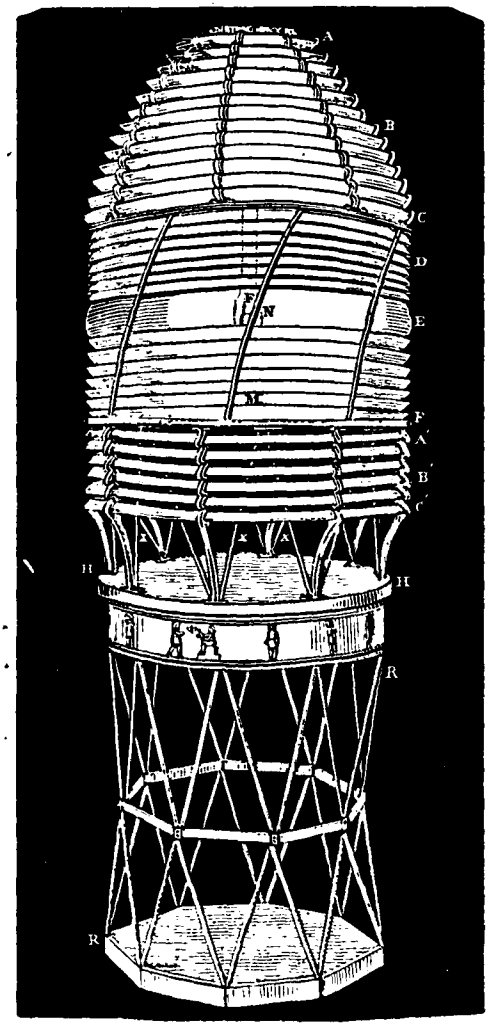
FIG. 348.



great flame in its focus being about 16; thus giving its increasing power as nearly equal to 180. The more perfect lenses have produced a considerably greater effect."

Fig. 348 represents the fixed catadioptric apparatus which was fitted up, under the direction of Mr. Stephenson, in the Skerryvore lighthouse, and in which the flame, instead of being enclosed in an

FIG. 349.



octagonal hollow prism, composed of compound lenses, is surrounded by a polygonal hoop, consisting of a series of narrow refractors having their axes in planes parallel to the horizon. The central dioptric

belt of refractors, DEF, forms a hollow cylinder 6 feet in diameter, and 30 inches high; below it are six triangular rings of glass, A′B′C′, or catadioptric zones, ranged in a cylindrical form, and above, 13 rings, A B C, gradually converging towards the summit; the whole structure forming a cage of glass 10 feet high by 6 in diameter. F is the focus where the lamp is placed, xxx are supports for the upper catadioptric zones. This arrangement distributes a zone of light equally brilliant in every point of the horizon.

Peclet, in his celebrated work upon Illumination, mentions that these or similar methods of illumination might be used with advantage in theatres, which are often very inadequately lighted. The position of the chandelier at the height of the upper boxes dazzles those occupying that position to such a degree, that the middle of the stage is to them quite darkened. Locatelli succeeded in obviating this evil about the year 1825, in the Theatre Fenice, at Venice, and in a manner which appears to be as ingenious as it is worthy of imitation. The chandelier is there placed in a round opening in the ceiling, therefore quite without the theatre, and in such a position that the burner cannot be directly seen from any point. An apparatus constructed with parabolic mirrors throws the light as a cylindrical bundle downwards into this opening, where a second arrangement of dispersing lenses spreads it in all directions over the space below.

It is obvious that all arrangements for reflecting or deadening the light must themselves entirely absorb a portion.

GAS ILLUMINATION.

Of all the applications of chemistry to the useful arts, none is, perhaps, more generally appreciated than the production of artificial light from carbonaceous matters; nor can we remember a more striking illustration of the time that often passes before a scientific germ is developed into a useful fact, than is exhibited in the early history of illuminating gas.

Historical Notes.—Numerous instances, both in ancient and modern times, are on record of the spontaneous discharge of combustible gases from fissures in the earth, and there is reason for supposing that some of these natural jets of gas were treated by the ancients as objects of veneration, as they still are by the inhabitants of parts of Persia and India, while the practical Chinese have for centuries employed similar combustible exhalations for evaporating salt-

brine and lighting their salt-works. In speaking of the nature and sources of fire-damp (p. 511), we have noticed the principal localities where these have been observed, and also alluded to their connection with the decomposition of vegetable matter in the soil. That these processes are still active under certain conditions, is proved by the formation of light carburetted hydrogen in every stagnant pool, and by the occasional discovery of accumulations of gas in boring for water. A remarkable occurrence of the latter kind took place in 1851, on Chat Moss, between Manchester and Liverpool, at about 35 feet below the surface, where, on the introduction of a pipe 10 or 12 inches in diameter, and 36 feet high, into the bore-hole, the gas was conducted above the forest trees, and, when ignited, produced a flame 8 or 10 feet long.

These natural exhalations of gas, consisting principally of light carburetted hydrogen, never afford a very luminous flame; and this, perhaps, accounts in some measure for the fact that, although their origin was traced by Shirley as early as the year 1659, to subjacent coal-beds, no attempt was made to apply either the gas or the coal to illuminating purposes for nearly a century and a half. Spirit of coal was, however, obtained from that substance, as early as the latter half of the 17th century, by Dr. Clayton, Rector of Crofton, at Wakefield in Yorkshire, who communicated his discovery in a letter to the Hon. Robert Boyle, which was not published in the "Transactions of the Royal Society" until the year 1739. The spirit or gas was obtained by distilling coal in a retort, was collected in bladders, and its combustible and illuminating properties exhibited; yet, notwithstanding this proof of its value, no practical application of the gas as a source of light appears to have suggested itself to the discoverer. In the "Vegetable Statics" of Dr. Hales, published in 1726, a quantitative experiment upon the amount of gas evolved during the distillation of Newcastle coal is described, which coincides in a remarkable manner with the actual produce of gas from the same kind of coal at the present day. From 158 grains of coal, Dr. Hales obtained 180 cubic inches of air, weighing 51 grains, or at the rate of 10,337 cubic feet per ton. In 1767, Dr. Watson also published experiments upon the quantity of gas yielded by coal, and ascertained that its volume and combustibility were not altered by passing through water. Amusing experiments were also made with the gases evolved from coke furnaces, by the Earl of Dundonald, in 1786, but no practical

application was made of these discoveries, until Mr. William Murdoch, in the year 1792, lighted his own house, at Redruth in Cornwall, with coal-gas distilled from iron retorts, and conveyed in metal pipes for a distance of 70 feet. This was undoubtedly the first useful application of a discovery which had been made at least a century before, and the success which attended it, and the subsequent labours of Mr. Murdoch, soon resulted in the general introduction of gas, as the best and cheapest source of light, wherever any considerable amount was required. It is but just to mention that the application of the gas obtained from the distillation of wood, was proposed independently, and coeval in time with Murdoch's invention, by Le Bon in France, who both lighted and heated his house by that means. The inferior quality of this gas, however, has never allowed it to come into competition with that obtained from coal. One great obstacle to the introduction of this source of light into private dwellings, had, however, still to be overcome, and this lay in the offensive and injurious properties of some of the products evolved during the combustion of the gas. These, though small in amount, it was found absolutely necessary to remove, either by conveying the whole of the products of combustion to the exterior of the building, or by separating from the gaseous mixture, before it entered the burners, those substances to which the noxious products owed their origin. The former plan was resorted to in many instances, and ventilating burners employed, which effectually removed to the chimney of the room, or elsewhere, the entire products of combustion. It was not long, however, before an agent was discovered, which to a very great extent removed the sources of the noxious products; and to Dr. Henry, and Mr. Clegg we are indebted for the suggestion of lime as a purifier, which still continues to be employed, often exclusively, for this purpose.

In 1792, Mr. Murdoch lighted his own house with coal-gas; in 1798, a part of the Soho Manufactory of Messrs. Boulton and Watt was lighted with the same material, where, on the occasion of the general illumination at the Peace of Amiens in 1802, a public exhibition of the light was made. Shortly afterwards, the cotton-mill belonging to Messrs. Phillips and Lee was wholly lighted with gas by Mr. Murdoch, whose experiments on the application of coal-gas to illumination were published in the "Philosophical Transactions, for 1808." Many private manufactories in the country, and the Stoneyhurst College, were lighted about this time by Messrs. Murdoch and Clegg; and Mr. Winsor's

indefatigable advocacy of gas-light in London soon led to its introduction into the Lyceum Theatre, and shortly afterwards one side of Pall Mall was similarly illuminated. The great advantages of gas-light for streets and public edifices then became apparent, and before many years the entire metropolis, and most provincial towns, were lighted with gas.

In the year 1815 gas-light was introduced in Paris. In the same year Mr. John Taylor secured a patent for obtaining illuminating gas by the distillation of oils and other similar materials; and for some time many extensive establishments adopted his process, which yielded a very superior gas, but at a cost which could not compete with that obtained from coal; and the use of this material was relinquished in this country, although it is still employed in some parts of the continent. In 1819 a patent was obtained by Mr. Gordon for compressing gas, so as to render it portable, but this scheme was also abandoned after a few years. The same fate befel the application of resin to the manufacture of gas, a short account of which will be given below, in connection with a recent revival of the process, by the Hydrocarbon Gas Company. The chief parts of the apparatus employed in the manufacture of coal-gas have remained in use since their introduction by Mr. Clegg, although many have been improved in detail, and others added for special purposes.

The extent and gradual increase of the consumption of gas in the metropolis is thus stated in Ure's Dictionary for the year 1852:—

For lighting London and its suburbs with gas, there are 18 public works, belonging to 12 companies, employing a capital, sunk in works, pipes, tanks, gas-holders, and apparatus, of £2,800,000, producing a yearly revenue of £450,000. The number of private burners, supplied to about 40,000 consumers, is 134,300, while there are 30,400 street lights, about 2650 being in the city of London; 380 lamplighters are employed, and about 2500 persons connected with the works. There are 176 gas-holders, capable of storing 5,500,000,000 cubic feet of gas. The quantity of coal consumed in the shortest day amounts to 890 tons in the twenty-four hours. The quantity of gas consumed in the longest night is about 7,120,000 cubic feet. Between 1822 and 1827, the quantity consumed was nearly doubled; between 1827 and 1837 it was again doubled. The consumption of coal for the supply of gas to the metropolis during the year ending June 1852 was almost exactly 408,000 tons, which on an average would yield 4,000,000,000 cubic feet of gas. Notwith-

standing this rapid increase of consumption, gas is by no means so general a source of light in the private houses of the metropolis as it is in Scotland and the north of England,—a circumstance which may be accounted for in some measure by the fact that until recently Newcastle bituminous coal was almost exclusively employed, which yields gas of an inferior quality as compared with the cannel coal used in the north, and sufficient attention was not paid to the purification. The London companies are, however, rapidly improving the quality of their gas by introducing Boghead and other cannel coals, which increase its illuminating power, while the processes of purification have now attained such a pitch of perfection as to render the products from the combustion of gas quite as innoxious as those from other illuminating materials: little doubt can therefore be entertained, that the consumption will increase in a more rapid ratio than heretofore.

It will be evident from the perusal of what has been already stated upon the general principles of illumination (pp. 385, 471), that the illuminating properties of a gas or mixture of gases must depend upon the relative proportions in which carbon and hydrogen enter into its composition; that it can only be usefully employed as a source of light when it contains a larger proportion of carbon than is contained in fire-damp; and that its value will increase as its composition more nearly resembles that of olefiant gas.

Light carburetted hydrogen (C_2H_4) contains 75.4 carbon to 24.6 hydrogen; olefiant gas (C_4H_4), 86 carbon to 12 hydrogen. The proportions of the elements in the latter gas render it well adapted for illuminating purposes, could it be procured at a sufficiently cheap price. This, however, is not the case; and we are obliged to be content, from motives of economy, with a mixture of gases, which contains so much olefiant gas that it far exceeds light carburetted hydrogen in illuminating power, and is produced by the decomposition of certain substances of organic origin. When these organic substances are exposed to a certain temperature in closed vessels, the following process results:—A carbonaceous residue (coke) remains in the vessel, while certain volatile products escape, a portion of which are condensed on cooling into tar and an aqueous fluid, the remainder being a mixture of gases, with a considerable proportion of the volatile vapours of the different compounds, the greater part of which have been condensed with the tar. The accompanying scheme will give at one view the nature of the products resulting from this process.

Fixed residue:—Coke containing carbon and the ash of the coal.

- **Volatile Matters.**
  - **Liquids, condensed and collected in tar-cistern**
    - **Coal-tar gives on redistillation with water or steam**
      - **Distilled tar; which affords**
        - **Pitch; distilled in ovens, affords**
          - Pitch coke.
          - Coke oil.
        - **on further distillation. Dead, or pitch oil, consisting of**
          - Naphthaline, paranaphthaline, and oily hydrocarbons boiling at a high temperature, creosote, aniline, leucoline.
      - **Crude coal-tar naphtha, which consists of**
        - Acids—Rosolic, carbolic, brunolic, creosote.
        - Bases of the pyrol, picoline, aniline, leucoline, methylamine, ethylamine, and other series.
        - Neutral—Alliole, benzole, toluole, cumole, cymole, & other carbohydrogens; naphthaline, hydrate of phenyle (Laurent).
    - **Ammoniacal liquor containing**
      - Water, hydrosulphate of ammonia, carbonate of ammonia, muriate of ammonia, acetate of ammonia, hydrocyanate of ammonia, sulphite of ammonia, gallate of ammonia.
  - **Gases and vapours**
    - **Gases and vapours separated in lime-purifier**
      - Carbonic acid.
      - Sulphuretted hydrogen.
      - Hydrocyanic acid.
      - Ammonia.
    - **Gases and vapours separated sometimes by additional chemical agents**
      - Ammonia.
      - Hydrocyanic acid.
    - **Gases and vapours conducted to gas-holder**
      - Olefiant gas.
      - Vapours of hydrocarbons.
      - Light carburetted hydrogen.
      - Hydrogen.
      - Carbonic oxide.
      - Very small quantities of
        - Nitrogen.
        - Vapour of bisulphuretof carbon.
        - Ammonia.

The researches of Sell, Blanchet, Runge, Kidd, Reichenbach, Hofmann, Anderson, Mansfield, and others, upon coal-tar, have led to the knowledge of a number of oily volatile products of very different chemical constitution, most of which are compounds of carbon with hydrogen. To these we shall revert particularly in treating of the secondary products of the gas manufacture; and for the present it is only necessary to remark that they contain a very large proportion of carbon, ranging from 90 to 94 per cent, and in burning, deposit it in still greater quantity than olefiant gas. It is obvious, therefore, why a portion of the vapours of these substances remaining in the gas should so much enhance its value. Omitting all notice, for the present, of the noxious and useless gases which are separated in the process of purification, we have, therefore, to consider illuminating gas, not as a definite compound, nor as light carburetted hydrogen or olefiant gas, but as a mechanical mixture of several gases and vapours, some of which are little if at all luminous, while to the others, including olefiant gas and the carbo-hydrogens which possess similar properties, the mixture is indebted for its illuminating power. The compounds of carbon and hydrogen are remarkable for uniting in the same proportions by weight to form a series of solids, liquids, and gases, possessing very different physical properties, according to the amount of contraction of volume which their elements have undergone in the moment of combination. Thus, among solids, naphthaline and paranaphthaline both contain carbon and hydrogen in the relative proportions of C_5H_2, but the densities of their vapours, their boiling points, and relation to other similar bodies, render it apparent that these numbers must be multiplied by 4 in the first, and by 6 in the second, so that they are represented by $C_{20}H_8$ and $C_{30}H_{12}$ respectively.

Among the liquid hydrocarbons, a great number possess very dissimilar physical properties, and yet exhibit the same percentage composition; thus, the composition of the oils of turpentine, of lemons, roses, juniper, some of the naphthas from tar, and many others, are represented by the crude formula C_5H_4; or, indeed, the formula $C_{20}H_{16}$ appears equally applicable to the whole. The gas obtained from the distillation of oil has the same composition in 100 parts as olefiant gas, but its density indicates that it contains double the number of atoms; while the one is represented by C_4H_4, the other is assigned the formula C_8H_8. Coal, wood, fats, turf, oils, resin and tar, asphaltum, soap-water, and the refuse of animal bodies, have all been proposed for the manufacture of

illuminating gas. Of the adaptation of some of these to that purpose we have already spoken: the locality exerts considerable influence upon the relative values of others, and as the different nature of these substances demands a different mode of treatment in preparing the gas, each must be separately discussed.

Gas Coal.—The nature of the coal which is submitted to distillation in the manufacture of gas exerts such a decided influence upon both the quantity and quality of the gaseous product, that notwithstanding the numerous and extensive series of coal analyses already contained in former sheets of this volume, we consider it absolutely indispensable to add others made especially with reference to the coal used for gas-making; and for these we are principally indebted to the author of the "Chemistry of Gas Lighting," in the journal devoted to that subject, and to the recent work of Mr. Hughes on "Gas Works."

The following table embraces information upon nearly all the varieties of coal employed in the united kingdom for the manufacture of gas, stating their specific gravities, the amounts of volatile matter, coke, and ash yielded in the retort, with the quantities of sulphur contained respectively in the coal, volatile matter, and coke; and nature of the ash.

	Name of Coal.	Spec. Grav.	Volatile Matters	Coke	Ash.	Nature of Ash.	Sulphur in Coal.	Sulphur in Coke	Sulphur in Volatile Matters
Pure Cannel Coals.	Boghead	1.221	68.4	31.6	22.8	Silicate of alumina	0.53	0.08	0.45
	Kirkness	1.208	60.	40.	13.5	Silicate of alumina and oxide of iron	1.4	0.58	0.82
	Capeldrae ...	1.2275	54 5	45.5	10.5	Silicate of alumina	0.65	0.20	0.45
	Old Wemyss .	1.3256	52.5	47.5	15.1	Oxide of iron and silicate of alumina	1.30	0.60	0.70
	Lesmahago ...	1.222	49.6	50.4	9.1	Silicate of alumina and oxide of iron	2.25	1.14	1.09
	Knightswood	. —	48.5	51.5	2.4	Oxide of iron and silicate of lime, with alumina	1.1	0.61	0.49
	Armiston.....	1.1967	45.5	54.5	4.18	Silicate of lime, alumina, and oxide of iron	1.70	0.95	0.75
	Wigan	1.271	37.0	63.0	3.0	Oxide of iron and silicate of alumina	1.25	0.60	0.65
	Ramsay's Newcastle	1.290	36.8	63.2	6.6	Oxide of iron and silicate of lime, with alumina	1.75	0.94	0.81

Name of Coal.	Spec. Grav.	Volatile Matters	Coke.	Ash.	Ash in Coke per cent	Sulphur in		
						Coal.	Coke.	Volatile Matters
Lochgelly Cannel	1.320	33.5	66.5	13.1	29.7	0.75	0.25	0.5
New Brunswick Cannel (Asphaltum)	1.098	66.3	33.7	0.6	1.78	0.7	0.0	0.7
Pelton Main	1.270	28.4	71.6	1.41	1.96	1.1	0.62	0.48
Pelton Main Cannel	1.320	31.5	68.5	9.4	13.7	0.95	0.49	0.46
Leverson's Wallsend	1.278	34.9	65.1	4.9	7.52	1.3	0.65	0.65
Leverson's Wallsend Cannel	1.320	30.8	69.2	9.35	13.67	1.0	0.5	0.5
Washington	1.260	31.25	68.75	2.2	3.2	1.3	0.67	0.63
Washington Cannel	1.326	27.4	72.6	9.37	12.9	1.1	0.56	0.55
Pelaw Main	1.271	30.3	69.7	2.60	3.7	1.2	0.7	0.5
Urpeth	1.271	28.7	71.3	1.35	1.89	1.0	0.6	0.4
New Pelton	1.265	30.2	69.8	1.71	2.5	1.1	0.56	0.54
Dean's Primrose	1.261	29.25	70.75	2.4	3.4	1.4	0.71	0.69
Stavely (Derbyshire)	1.275	40.9	59.1	2.7	4.57	1.2	0.8	0.4
Elsecar Low Pit (Yorkshire)	1.258	37.0	63.0	1.1	1.74	1.2	0.63	0.57
Griglesto nCliff, soft (Yorkshire)	1.255	35.6	64.4	1.6	2.48	1.4	0.75	0.65
Silkston, No. 1 (Yorkshire)	1.26	34.1	65 9	2.78	4.2	1.3	0.8	0.5
Silkston, No. 2 „	1.259	38.0	62.0	2.55	4.1	1.1	0.6	0.5
Silkston, No. 3 „	1.262	35.2	64.8	2.8	4.3	1.45	0.75	0.7
Arley (Lancashire)	1.270	33.7	66.3	3.6	4.8	1.2	0.6	0.6
Heathern (Staffordshire)	1.280	42.9	57.1	1.75	3.0	1.5	0.7	0.8
Coal-pit Heath (Gloucestershire)	1.370	30.1	69.9	5.8	8.3	4.1	2.2	1.9
Radstock (Somersetshire)	1.275	38.25	61.75	3.5	5.6	3.1	1.8	1.3
Rhonda (South Wales)	1.278	22.8	77.2	2.7	3.5	2.3	1.2	1.1
Denain (Valenciennes, France)	1.265	23.9 ?	70.1	6.0	3.5	2.4	1.3	1.1
West Hartley	1.269	35.8	64.2	4.7	7.3	1.1	0.6	0.5
Hastings Hartley	1.278	36.5	63.4	2.0	3.1	0.95	0.5	0.45
Gosforth	1.260	35.0	65.0	1.	1.5	1.1	0.5	0.6
South Peareth	1.266	27.8	72.2	1.8	2.5	1.2	0.6	0.6
Garesfield (Bute's)	1.290	28.3	71.7	3.2	4.4	0.9	0.4	0 5
Garesfield (Cowan's)	1.259	29.4	70.6	0.95	1.3	0.85	0.4	0.45
South Tyne	1.339	36.3	63.7	3.9	6.1	2.1	1 1	1.0
Blenkinsopp	1.298	38.0	62.0	5.1	8.2	1.6	0 8	0.8
Woodthorpe (South Yorkshire)	1.347	33.1	66.9	10.5	16.6	1.2	0.7	0.5
Soap House Pit ditto	1.258	35.0	65.0	0.8	1 2	0.75	0.4	0.35
Mortomly ditto	1.220	37.0	63.0	1.6	2.5	1.1	0.6	0.5
Cumberland, No. 1	1.294	25.5	74.5	2.1	2.8	1.3	0.7	0.6
Cumberland, No. 2	1.275	25.6	74.4	1.4	1.9	1.1	0.6	0.5
Cumberland, No. 3	1.290	30.9	69.1	4.0	5.8	1.7	0.8	0.9
Ruabon Nant Seam (N. Wales)	1.269	37.9	62.1	1.4	2.2	1.1	0.7	0.4
Ruabon Top Yard Seam ditto	1.269	37.5	62.5	2.5	4.0	1.4	0.8	0.6
Ruabon Main Coal ditto	1.284	41.5	58.5	1.0	1.7	0.85	0.45	0.4
Ruabon Yard Seam ditto	1.271	34.0	66.0	1.4	2.1	1.1	0.6	0.5
Rhonda Low Main (S. Wales)	1.280	23.1	76.9	2.1	2.7	2.2	1.1	1.1
Nailsea (Somersetshire)	1.312	34.9	65.1	3.0	4.6	2.85	1.5	1.35
Silverdale, 10 feet (N. Stafford.)	1.301	34.0	66.0	1.95	2.92	1.3	0.7	0.6
Woodshutts, 7 feet, Banbury (N. Staffordshire)	1.291	40.2	59.8	1.22	2.03	0.9	0.54	0.36
Apedale (N. Staffordshire)	1.307	38.5	61.5	1.9	3.1	1.5	0.82	0.68
Apedale, 4 feet (N. Stafford.)	1.287	40.0	60.0	0.75	1.25	0.80	0.38	0.42
Harecastle (Cheshire)	1.230	31.5	68.5	5.0	7.3	2.1	1.1	1.0
St. Helen's (South Lancashire)	1.285	37.2	62.8	1.2	1.91	1.1	0.54	0.56
Staffordshire Cannel	1.220	50.0	50.0	2.9	5.8	1.3	0.52	0.78
Whitecroft (near Sydney, Gloucestershire)	1.401	34.3	65.7	11.1	16.8	3.1	1.9	1.2

The following results of Drs. Maclagan, Richardson, and Penny, made public on the occasion of the late trial respecting the nature of Boghead coal or Torbanehill mineral, will corroborate the foregoing table, and complete the list of cannel coal analyses.

ANALYSES OF COALS AND SHALES BY DR. DOUGLAS MACLAGAN, OF EDINBURGH.

Locality.	Sp. Gr.	Volatile Matter.	Coke, consisting of		Composition of Ash.
			Fixed Carbon.	Ash.	
1. Boghead Coal, Mean of Three Experiments	1.209	69.70	7.73	22.57	Silica, 69. Alumina, Oxide of Iron, Lime, Magnesia, &c. 31–100.
2. Lesmahago Parrot Coal, Mean	1.230	51.44	39.57	8.98	Silica, 48. Alumina, &c. 52–100.
3. Capeldrae Parrot Coal	1.321	50.00	33.90	16.10	Silica, 53. Alumina, &c. 47–100.
4. Balbardie Parrot Coal	1.443	52.05	21.28	26.67	Silica, 70: Alumina, &c. 30–100.
5. Methill Parrot Coal	1.147	69.43	21.84	8.72	
6. Rochsoles Co.'s Parrot Coal	1.161	70.59	13.14	16.27	
7. Fife Parrot Coal, No. 1	1.430	45.50	32.55	21.95	
„ No. 2	1.327	46.56	39.55	13.89	
8. Cherry Coal, from Torbanehill Parrot	...	42.16	40.90	16.94	Silica, 65. Alumina, &c. 35–100.
9. Torbanehill Top of House Coal	1.327	32.27	64.80	2.92	
10. Torbanehill Bottom of House Coal	1.401	28.11	42.22	27.28	Silica, 78. Alumina, &c. 22–100.
		Combustible Matter, Moisture.			
11. Shale, from Stirlingshire Coal Field	2.344	16.53	...	83.47	Silica, 78. Alumina, &c. 22–100.
12. Birtledean Shale, Lancashire	2.390	16.84	...	83.16	Silica, 82. Alumina, &c. 18–100.
13. Pendleton Shale, ditto	2.642	22.52	...	77.47	
14. Fife "Rums"	1.694	26.74	20.51	52.75	

SCOTCH COALS, ASSAYED BY DR. RICHARDSON, OF NEWCASTLE.

Boghead Coal, Top of Seam	...	64.62	15.22	20.16
„ Bottom of do.	...	67.59	10.90	21.51
Rochsoles Co.'s Coal	...	63.94	17.95	18.11
Methill Coal	...	63.68	18.82	17.50

VARIOUS CANNEL COALS, ANALYSED BY DR. PENNY.

CANNEL or PARROT COALS.	COAL.						COKE.		
	Sp. Gr.	Volatile Matters	Fixed Carbon.	Ash.	Sulphur.	Water.	Total Amount of Coke in Coal.	Carbon in Coke.	Ash in Coke.
		Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
1. Rochsoles (1851)	1.448	53.7	4.9	38.8	1.6	1.	42.3	11.58	88.42
2. Hardie's (1852)	1.420	34.	4.	58.4	*	3.5	62.4	6.44	93.56
3. Boghead, Brown (1851)	1.160	71.06	7.10	26.2	.24	.4	28.3	25.09	74.91
4. Boghead, Black (1851)	1.2185	62.7	9.25	26.5	.35	1.2	35.75	25.88	74.12
5. Torbanehill (1853)	1.1892	67.11	10.52	21.	.32	1.05	31.52	33.38	66.62
6. Boghead (1849)	1.1550	71.3	11.3	16.8	(.34)	.6	28.1	40.22	59.78
7. Bathville	1.201	64.35	12.6	22.2	.25	.60	34.80	36.21	63.79
8. Stan (Ayrshire)	1.4647	52 08	14.77	32.	*	1.15	46.77	31.52	68.48
9. Methill	1.3002	49.23	17.57	29.7	*	3.50	47.27	37.17	62.83
10. Capeldrae	1.3603	45.73	19.97	31.5	*	2.80	51.47	38.80	61.20
11. Wemyss	1.1831	58.52	25.28	14.25	*	1.95	39.53	63.95	36.05
12. Balbardie (1852)	1.420	38.96	29 66	28.	.38	3.0	57.66	48.56	51.44
13. Hillhead (Kilmarnock)	1·602 / 1.320	36.65	32.34	27.4	.61	3.	59.74	54.14	45.86
14. Brymbo	*	32.10	36.4	29.4	*	2.1	65.80	55.32	44.68
15. Lesmahagow (Auchinheath)	1.1990	56.23	36.7	4.3	.55	3.15	41.	89.50	10.50
16. Bartonshill	1.280	48.	39.6	10.	2.	2.4	49.6	79.84	20.16
17. Bartonshill	1.350	38.	37.9	18.7	2.2	3.2	56.6	66.96	33.04
18. Stevenson (Ayrshire)	1.3850	40.21	40.14	19.35	*	.3	59.49	67.64	32.36
19. Lesmahagow (Southfield)	1.228	49.34	40.97	6.34	1.35	2.	47.31	86.60	13.40
20. Knightswood	1.234	44.77	41.13	11.05	*	3.05	52.18	78.83	21.17
21 Cairnbroe	1.247	42.83	42.67	8.50	*	6.	51.17	83.39	26.61
22. Skatorigg	1.252	49.32	44.83	2.50	*	3.35	47.33	94.42	5.58
23. Cowdenhill	1.299	46.0	45.	5.	.50	3.50	50.	90.	10.
24. Breadisholme	1.335	39.	48.5	8.1	.4	4.	56.6	85.69	14.31
25. Ruchill	1.223	45.73	49.27	2.5	*	2.5	51.77	95.17	4.83
26. Kelvinside	1.231	40.17	53.42	1.9	.21	4.3	55.32	96.57	3.43

* Not estimated.

The inspection of these tables shows that the cannel coals yield, on distillation, a very much larger amount of volatile matter, less coke, a larger quantity of ash, and generally more sulphur, than the bituminous class, while no anthracite is included in the table from the circumstance of its affording little or no volatile matter, and, therefore, being quite inapplicable to gas making.

With reference to the volatile matter produced from cannel coal, we shall also find that it is of superior quality for illuminating purposes, while the coke is often so intimately mixed with earthy matter, or contains so little carbon and combustible matter, as to be of little or no value as fuel.

The ash of the cannels will be found to consist chiefly of silicate of alumina, and has been observed to bear a remarkable analogy to decomposed felspar, from which a portion of silicate of potash has been washed out; leading to the inference, when considered in connection with its large relative amount, that these varieties have been formed by the decomposition of an accumulation of the lower order of vegetables, such as mosses, lichens, sea-weed, &c., deposited with the débris of the older rocks; while the occurrence of muriate of ammonia, and occasionally of hydriodate of ammonia, as observed by M. Bussy in the coal and products of distillation, point to a marine origin of the vegetable remains, or to a submergence below the waters of the sea.

The ash of bituminous coal consists generally of silicate and sulphate of lime, with oxide of iron and some argillaceous matter, the greater portion of which may have formed the natural ash of the large trees to which the formation owes its origin, and which are known to belong to a class (*Equisetaceæ*), yielding a silicious ash.

The sulphur will be generally found, with some marked exceptions, in larger quantity in the cannels than in the bituminous coals, and a larger portion passes off with the volatile ingredients on distillation, part being in the form of sulphuretted hydrogen, but more as the bisulphuret of carbon. This circumstance has led to the conclusion that the sulphur in cannel coal is not derived exclusively from iron pyrites, as in bituminous coal, but exists in some other form of combination, from which it is evolved at a lower temperature, and thus enabled to enter more readily into combination with carbon. Bituminous coal is never entirely free from iron pyrites, or the bisulphuret of iron, and when much water is mechanically mixed with the coal as it is placed in the retort, or there is a large proportion of oxygen in its composition, which produces water with the hydrogen, and particularly if a very high temperature be employed in the process, this ingredient is converted, by mutual decomposition with steam, into peroxide of iron and sulphuretted hydrogen. Carbonate of lime frequently accompanies the layers of coal, forming thin bands between the seams, and may often be of service to the gas-maker in diminishing the amount of sulphuretted hydrogen evolved. At the temperature of the gas retort the carbonic acid is expelled, which becomes partly converted into carbonic oxide by contact with red-hot coke, while the calcium combines with the sulphur of the

sulphuretted hydrogen, becoming sulphuret of calcium, which remains in the coke.

Although prejudicial as a source of carbonic acid and carbonic oxide, carbonate of lime may thus effect a partial separation of sulphur from the gas.

It is a most fortunate circumstance that no compounds of arsenic have been ever found associated with the iron pyrites of the coal fields, although they frequently accompany this mineral in other formations. Had this not been the case, a most serious objection would have arisen to the use of coal-gas for domestic purposes, and great difficulties have been thrown in the way of its purification, even if sanitary precautions would ever have permitted a gas to be used which was liable to evolve in burning so virulent a poison as arsenious acid.

The natural moisture in the coal, which varies from 1 to 14 per cent in different samples, is a serious obstacle to contend with in gas-making, as to it the greater portion of the carbonic acid which accompanies the gaseous mixture must be attributed, and the cost of purification becomes proportionally increased. Aqueous vapour in contact with red-hot charcoal becomes converted into carbonic acid and carburetted hydrogen, while the bisulphuret of iron is much more readily converted in its presence into sulphuretted hydrogen and the peroxide.

It will at once be seen from the foregoing tables, that cannel coal is very far superior to all others in the proportion of volatile matter yielded; but as all the volatile matter afforded by coal is not combustible, it does not necessarily follow that the coal which yields the largest amount of gas is the most valuable gas coal, although such is generally the case, as will be seen by the following tables taken from Mr. Hughes on "Gas Works."

Description of Coal.	Cubic feet of gas per ton of coal.	Specific gravity of the gas.	Weight of gas in lbs. avoir-dupois per ton of coal.	Authority.
Newcastle Coals.				
English Caking Coal	8,000	.420	257	Dr. Fyfe.
Newcastle Coal	11,648	.475	423	Mr. Joseph Hedley.
Pelaw, Newcastle	11,424	.444	389	Ditto.
Pelton, ditto	11,424	.437	382	Ditto.
Blenkinsopp, Carlisle	11,200	.521	447	Ditto.
Newcastle	8,500	.412	268	London, 1837.
Wallsend, Newcastle	12,000	.490	450	Quantity made in the revolving web retort; authority, Mr. Clegg.
Pelton	11,000	.430	363	Author of the "Chemistry of Gas-Lighting," in the "Journal of Gas-Lighting."
Leverson	10,800	.425	353	
Washington	10,000	.430	330	
Pelaw	11,000	.420	355	
New Pelton	10,500	.415	335	
Dean's Primrose	10,500	.430	347	
Garesfield	10,500	.398	321	
Gosforth	10,000	.402	308	
West Hartley	10,500	.420	339	
Hasting's Hartley	10,300	.421	333	
Blenkinsopp	9,700	.450	335	
Berwick & Craister's Wallsend	12,507	.470	449	Mr. Clegg.
Pelaw Main	12,400	.420	399	Ditto.
Russell's Wallsend	12,000	.418	384	Ditto.
Ellison's Main	11,200	.416	357	Ditto.
Felling Main	11,200	.410	351	Ditto.
Pearith's Wallsend	11,147	.410	350	Ditto.
Dean's Primrose	11,120	.410	349	Ditto.
Benton Main	10,987	.400	337	Ditto.
Eden Main	10,400	.400	318	Ditto.
Heaton Main	10,400	.410	326	Ditto.
	9,000	...	...	Average production by Phœnix Gas Company for year 1848.
Parrot or Cannel Coals.				
Yorkshire Parrot	11,500	...	...	Dr. Fyfe.
Wigan Cannel	9,500	.460 to .520	357	Ditto.
Scottish Parrot	9,500	.640	466	Ditto.
Ramsay's Newcastle Cannel	9,746	.554 to .580	423	Ditto.
Loch Gelly Parrot	9,128	.567	396	Ditto.
Lesmahago Cannel, 1st experiment	11,681	.540	483	Mr. Wright.
Ditto, ditto, 2nd experiment	9,878	.650	492	Ditto.
Ramsay's Newcastle Cannel	9,016	.604	417	Ditto.
Ditto ditto	9,333	.598	427	John Kay, Manager of Dundee Gas Works.
Ditto ditto	9,667	.731	541	Dr. Leeson, Dr. Miller, and Mr. G. H. Palmer.
Lesmahago Cannel	11,312	.737	638	Mr. Joseph Hedley.
Welsh Cannel	11,424	.737	645	Ditto.

Description of Coal.	Cubic feet of gas per ton of coal.	Specific gravity of the gas.	Weight of gas in lbs. avoirdupois per ton of coal.	Authority.
Parrot or Cannel Coals—cont.				
Wigan Cannel	11,200	.606	520	Mr. Joseph Hedley.
Ditto ditto	9,500	.580	422	Liverpool New Gas and Coke Company.
Wemyss Cannel	10,976	.670	563	Mr. Wright.
Ditto ditto	10,192	.691	538	Ditto.
Wigan Cannel	9,408	.478	344	Ditto.
Knightswood Cannel	9,720	.590	439	Ditto.
Boghead Cannel	15,000	.752	866	Mr. J. Evans, at Westminster Station of Chartered Gas Company.*
Lesmahago, No. 1	13,500	.642	666	Ditto.
Ditto No. 2	13,200	.618	627	Ditto.
Capeldrae Cannel	14,400	.577	638	Ditto.
Arniston Cannel	12,600	.626	606	Ditto.
Ramsay Cannel	10,300	.548	433	Mr. J. Evans.
Wemyss Cannel	14,300	.580	637	Ditto.
Kirkness Cannel	12,800	.562	552	Ditto.
Knightswood Cannel	13,200	.550	558	Ditto.
Wigan (Ince Hall) Cannel	11,400	.528	461	Ditto.
Pelton Cannel	11,500	.520	459	Mr. Joseph Hedley.
Leverson Cannel	11,600	.523	466	Ditto.
Washington Cannel	10,500	.500	403	Ditto.
Wigan Cannel	14,453	.640	708	Mr. Clegg.
Ditto ditto	14,267	.610	664	Ditto.
Scotch Cannel	14,000	.580	622	Ditto.
Ditto ditto	13,813	.500	529	Ditto.
Derbyshire, Welsh, Staffordshire, and other kinds of Coal.				
Derbyshire Deep Main	9,400	.424	308	Mr. Wright.
Brymbo 2-yard Coal	8,880	.463	315	Ditto.
Powell Coal, 2 cwt. charges every five hours	10,165	.459	357	Ditto.
Powell Coal, 1¼ cwt. charges every five hours	8,250	.470	296	Ditto.
Bickerstaff, Liverpool	11,424	.475	415	Mr. Hedley.
Neath, South Wales	11,200	.468	401	Ditto.
Birmingham Gas Company: Lump Coal from West Bromwich	6,500	.453	226	Birmingham Gas Company. Parliamentary return.
West Bromwich	6,500	.455	227	Birmingham and Staffordshire. Ditto.
Macclesfield	6,720	...	...	
Stockport	7,800	.539	322	Parliamentary return.
Oldham, Watergate, and Wigan Cannel mixed	9,500	.534	388	Manchester. Ditto.
Ormskirk, or Wigan Slack	8,200	.462	290	Liverpool, Old Company. Ditto.
Low Moor, mixed with two kinds of Slack	8,000	.420	257	Bradford. Ditto.
Leeds Coal	6,500	.530	263	Leeds Company. Parliamentary return.

* Each of the results given by Mr. Evans is the mean of three experiments.

Description of Coal.	Cubic feet of gas per ton of coal.	Specific gravity of the gas.	Weight of gas in lbs. avoir-dupois per ton of coal.	Authority.
Derbyshire Coals, &c.—cont.				
Cannel and Common Coal mixed	8,000	.466	285	Sheffield Company. Parliamentary return
Derbyshire Soft Coal	7,500	.528	303	Leicester. Ditto.
Ditto ditto	7,000	.448	240	Derby. Ditto.
Ditto ditto	7,000	.424	227	Nottingham. Ditto.
Staffordshire.				
South's	10,933	.398	333	Mr. A. Wright.
Second variety	10,667	.395	322	Ditto.
Third variety	10,667	.390	318	Ditto.
Fourth variety	9,600	.320	235	Ditto.
Forest of Dean	10,133	.350	271	Ditto.
Second variety	10,133	.360	279	Ditto.
Welsh Coal.				
First variety	10,000	.385	295	Ditto.
Second variety	10,133	.380	295	Ditto.

Some practical gas engineers are of opinion that the quantities in the above table are larger than are usually obtained in the works. The following table by Mr. Wright, in which the results of experiments on the distillation of cannel coals are placed in a very practical commercial form, will be found interesting.

	NAME OF COAL.						
	Lesmahago Cannel.		Ramsay's Newcastle Cannel.	Derbyshire Deep Main.	Wemyss Cannel.		Wigan Cannel.
	Exp. 1.	Exp. 2.			Exp. 1.	Exp. 2.	
	Pounds per ton.	Pounds per ton.	Pounds per ton.	Pounds per ton.	Pounds per ton.	Pounds per ton.	Pounds per ton.
Coke	1091.	1064.	1435.	1335.	1124.5	1188.	1326.0
Gas	463.	483.5	410.	300.	551.4	528.	338.0
Tar	594.	603.	295.	219.	224.0	197.	250.0
Ammonia and Water	4.5	4.5	6.72	179.	...	...	...
Loss	87.5	85.	93.28	207.	340.1	327.	326.0
	2240.	2240.	2240.	2240.	2240.	2240.	2240.
Cubic feet of Gas	11,681	9,878	9,016	9,400	10,976	10.192	9,408
Specific Gravity	0.540	0.650	0.604	0.424	0.670	0.691	0.478
Illuminating Power, Gas of Sp.gr. 0.86 being 1	...	2.33	2.	0.8	2.47	...	1.5

The following tables by Dr. Fyfe contain, in addition to the quantities of gas afforded by the coals, much valuable information upon the relative illuminating values of the gases, to the consideration of which we shall return in a future page.

COALS.	Cubic Feet of Gas per Ton.	Comparative Value of Coals per Ton, by Quantity of Gas.	Specific Gravity of Gas, Air = 1000.	Condensation by Chlorine per Cent.	Duration by Jet, Five-Inch Flame.	Comparative Value of Gas by Chlorine.	Comparative Value of Gas by Durability.	Comparative Value of Gas by Chlorine and Durability.	Comp. Value of Coals per Ton, taking Quantity of Gas condensed by Chlorine, and Durability, into account.
ENGLISH CANNEL:—					M. S.				
Yorkshire	11500	1.28	.451	7.66	45.	0.85	0.92.	0.78	1.00
SCOTCH CANNELS:—									
Knightswood	8960	1.00	.557	.9	48.	1.00	1.00	1.00	1.00
Lochgelly	9123	1.01	.567	14.5	65.30	1.66	1.36	1.95	1.11
Marq. Lothian	10000	1.11	.556	13.	60.	1.44	1.25	1.80	2.00
Torryburn	11200	1.24	.624	13.	57.30	1.44	1.19	1.71	2.13
Monkland	10190	1.13	.667	16.	67.	1.77	1.4	2.01	2.29
Arniston	10640	1.18	.637	17.5	68.30	1.94	1.41	2.03	2.41
Wemyss	10080	1.12	.642	19.5	75.	2 16	1.56	2.24	2.54
Kirkness	9620	1.07	.711	20.75	80.18	2.30	1.67	2.40	2.58

This table shows the quantity of gas afforded from a ton of each of the coals; the specific gravity of the gas; the amount of condensible matter by chlorine; the durability of the gas when burned by a single jet, with a five-inch flame; the comparative value of the gas for affording light, as shown by the chlorine test, by the durability, and by these taken together, which, when this test is had recourse to, is the proper method to follow. It shows also the comparative value of the coals for the purpose of illumination by the combustion of their gases, as proved by the quantity of gas afforded by each, and also by the quantity and quality taken together.

COALS.	Cubic Feet of Gas per Ton.	Specific Gravity of Gas, Air = 1000.	Condensation by Chlorine, per Cent.	Durability by Jet, Five Inch Flame.	Illuminating Power, 1 Foot, Sperm. Candles=120 grs. per Hour.	Value of 1 Foot in grains Sperm.	Comparative Value of 1 Foot in grains Sperm.	Value of 1 Ton of Coals in Pounds of Sperm.	Comparative Value of Coals.	Pounds of Coke per Ton of Coal.	Fixed Carbon per Cent in Coal.	Ashes per Cent in Coal.	Pounds of Sulphur per Ton of Coal.
ENGLISH CORING :—				M. S.									
Pelton	9746	555	6.5	50.40	3.125	382.2	1.	532.	1.	1563	—	—	—
ENGLISH CANNEL :—													
Ramsay's Newcastle.	9692	625	13.25	60.40	3.33	399.6	1.04	553.	1.04	1520	—	—	—
Wigan	12010	566	9.9	52.5	3.04	365.4	0.95	627.4	1.17	1360	55.	7.1	—
SCOTCH CANNEL :—													
Donibristle	9923	593	9.	51.5	7.51	901.2	2.35	1277.5	2.4	1220	49.22	4.28	8.5
Lesmahago	10176	669	17.	60.	8.77	1058.8	2.75	1539.	2.87	1360	42.44	4.	—
Capeldrae I. ..	11500	644	18.	65.25	8.312	997.4	2.61	1638 7	3.08	9999	33.2	7.7	7.7
Ditto II. ..	9670	650	17.8	73.37	10.01	1201.2	3.24	1670.3	3.18	1256	23.9	24.5	
Boghead	15426	726	23.37	84.44	10.38	1245.6	3.25	2755.6	4.3	760	9.25	21.75	3.

This table shows the quantity of gas afforded from a ton of each of the coals; the specific gravity of the gases; the amount of matter condensible by chlorine; the time that a cubic foot will burn from a single jet, with a flame of five inches in length; the illuminating power of the gas compared with that of a spermaccti candle consuming 120 grains per hour, as shown by Bunsen's photometer; and the value of a foot of gas in grains of spermaceti; also the value of a ton of coals for affording light by the combustion of its gas, given in lbs. of spermaceti; the quantity of coke and of sulphur per ton of coal; and the percentage of fixed carbon, and of ashes, are also given.

The decomposition of the coal begins a little below a red heat, and continues, when large quantities are employed, for several hours, the quantity of gas gradually diminishing towards the end. According to Peckston, in an eight hours' distillation the relative quantities of gas given off are, in the first hour 20, in the second 15, in the third 14, in the fourth nearly 13, in the fifth 12, in the sixth 10, in the seventh 9, and in the eighth about 8 per cent of the whole quantity, when the fire is uniform and the vessels are constantly at a red heat. The cubic foot at the end, therefore, costs $2\frac{1}{2}$ times as much as at the beginning. The quality of the

gas at the different periods of the distillation, however, must also be taken into consideration.

For this purpose it will be well again to direct attention to the ingredients of the gaseous mixture: this consists, after the separation of the tar and the aqueous liquid, of *olefiant gas, light carburetted hydrogen, carbonic oxide, hydrogen, vapours of the volatile oils of tar, sulphuret of carbon, ammonia, sulphuretted hydrogen, carbonic acid, cyanogen, sulpho-cyanogen, hydrochloric acid ?, aqueous vapour,* and *nitrogen.* The carbonic oxide and a part of the free hydrogen have doubtless the same origin, being formed from the moisture in the coal, or from the first portions of aqueous vapour that are generated passing over the red-hot coke. The nitrogen of the coal is converted entirely into cyanogen and ammonia, which are partly in combination, while the latter is also found combined with sulpho-cyanogen and the other acids forming volatile salts; the *free* nitrogen, on the contrary, is the residue of atmospheric air contained in the retort. Sulphuretted hydrogen and sulphuret of carbon are due to the sulphur and iron pyrites in the coal. The first four of the ingredients named, with the illuminating vapours of tar oil, form the proper bulk of the gas; the others are impurities, and being only present in small quantity, should have been separated in the process of purification. It has been found by experience that the relative proportions of these four ingredients vary with the duration of the distillation, and that the illuminating portion of the gas is evolved during the earliest stage of the process. When chlorine is added to coal-gas, it forms with the olefiant gas and the vapours of tar oil—with those constituents, therefore, upon which the illuminating power depends—a fluid compound, which separates, and the original volume is consequently diminished. The diminution which the volume of the gas suffers when mixed with chlorine is, therefore, in direct proportion to its illuminating power, and to the value of the gas—to the amount of olefiant gas (and tar oil vapours) which it contains. This explains a portion of the table of Dr. Fyfe, given above, and also the following experiments of Henry, who was the first to publish a correct and trustworthy description of the entire process of gas-making, by analysing carefully, step by step, the various products as they were evolved. Henry found that below a cherry-red heat, almost nothing but hydrogen, atmospheric air, and some tar, passed off, with hardly any illuminating gas, but at that temperature illuminating gas

alone appeared, and this was composed of a mixture of gases in the following relative proportions:—

Time of Collection.	Specific Gravity.	Absorbed by Chlorine.	Light Carburetted Hydrogen.	Carbonic Oxide.	Hydrogen.	Nitrogen.
		out of 100 parts of Gas from Wigan Cannel Coal.				
In the first hour	0.650	13	82.5	3.2	0	1.3
	0.620	12	72	1.9	8.8	5.3
	0.630	12	58	12.3	16	1.7
5 hours after the commencement	0.500	7	56	11	21.3	4.7
10 hours after the commencement	0.345	0	20	10	60	10

As a general result, therefore, the carburetted hydrogen is by far the most abundant product, and the most luminous portion, which is condensible by chlorine, comprises only about one-fifth of the whole. These numbers also prove distinctly that after about the fifth hour an addition to the quantity alone is made, while the quality does not improve, but, on the contrary, is so rapidly deteriorated, that at the expiration of ten hours the gas which passes over is hardly luminous when ignited, burning with a very faint blue flame. The specific gravity, as will also be seen, keeps pace with the quality of the gas, and can thus far be taken as a test of its value. As pure olefiant gas has about the specific gravity of the air (0.98), the density of an illuminating gas must increase with the quantity of olefiant gas contained in it; yet an extraordinary amount of carbonic oxide (sp. gr. = 0.97) or of carbonic acid (sp. gr. = 1.52) may give rise to errors of some magnitude. The immense increase of hydrogen, which at this last period amounts to 60 per cent, is remarkable, and very important to the manufacturer, as this increase is no longer due to the decomposition of aqueous vapours alone, but to that of the carbo-hydrogens themselves. In accordance with an old observation, these gases are decomposed at a high red heat, depositing a portion of their carbon on the sides of the vessel, and more recent experiments of Marchand show the progress of this decomposition very clearly. When olefiant gas was conducted through a red-hot tube and the heat constantly augmented, the gas passing off, collected in successive portions, contained the following quantities of carbon to 100 of hydrogen:—

Hydrogen : Carbon	Nature and Temperature of the Gas.	Hydrogen : Carbon	Nature and Temperature of the Gas.
100 : 614	Olefiant gas.	100 : 367	
100 : 580	Red heat.	100 : 325	Intense white heat.
100 : 533		100 : 307	Light carburetted hydrogen.
100 : 472		100 : 7	Continued white heat (nearly pure hydrogen).

It is evident that this decarbonisation is at last complete, and that the illuminating power of the gas must suffer in proportion. The amount of carbon deposited is found to increase with the degree of heat, the extension of the red hot sides of the retort, and the time that the gas is in contact with them. When the whole charge of a retort becomes converted into red hot coke, and even from the very commencement of the distillation, the retorts being maintained at a red heat, the carbo-hydrogens must always pass over red-hot surfaces before they can reach the conducting tube, and hence, although only for a short time, they deposit carbon.

The best product is obtained when dry coal only is used, and when the retorts are kept at a cherry-red heat throughout the process, the coke being discharged after the expiration of five or more hours, when the illuminating power of the gas begins to diminish. It must not be supposed, however, that the gas is directly produced from the coal, for observation leads to the conclusion that tar is the first product, which is subsequently decomposed and partially converted into gas. If the temperature does not rise above a red heat, tar is produced in great quantities, with little or no gas.

Before describing the various parts of the apparatus employed in the manufacture of coal-gas, it will be well to take a general survey of the various steps in the process, which will be rendered clear by referring to the plan and section of a French gas-work, Plate I., capable of distilling about 20 tons of coal in 24 hours.

The coal is placed in the retorts c c (Fig. 2), which are heated in furnaces D; the gaseous products pass off to the hydraulic main F, assisted by the exhausting apparatus, G (Fig. 3); they pass to the condensers *r r r r* (Fig. 5), where the tar collects in the receivers R R, and flows into a tar-well. On leaving the condensers the gases pass into the purifiers B B, where the useless and noxious portions

are separated, and thence to the gas-holder z, to be distributed into the mains.

The letters E E (Fig. 2) are metal tubes placed in the flues which carry off the waste products of combustion to the chimney A, and thus heat the air destined for the combustion of the coal. The hot air enters at *e* in the ash-pit for the use of the furnace D; and the flame heats the retorts C C, when it passes down by the flue *h h'* to the chimney. The saving of fuel is such that only 12 cwts. of coke are consumed during the same time.

A large underground flue M conveys all the products of combustion to this one chimney; and to avoid any danger from the excessive heat accumulating in one spot, a current of air is made to descend through the small openings *a a* (Fig. 1') of a metal plate which covers a large recess A. It passes through a tube *d* into a vault *b*, where it carries off the excess of heat, passing out again through the pipes *c e*, *e' e''* into the chimney.

The gases pass from the retorts by a pipe *i*, which dipping into the water in the main pipe E, interrupts the direct communication between the retorts and the rest of the apparatus. A quantity of water and tar condenses in this main pipe, which allows the excess to flow off continually through a water luted syphon. The pressure which this arrangement exerts on the retorts is obviated by the plan at present adopted, to pump out the gas as it is produced. In some establishments an Archimedean screw, in others, apparatus on the principle of the disc engine, are employed for this purpose.

The plan adopted at Paris consists in employing three cylinders G G G (Fig. 3) which rise and fall alternately by means of the cog-wheels *k*; the gas enters from the main pipe F through the tubes L H K, and leaves by the pipes K K *k'*, passing through I, thence through J N N to the regulator M.

When the gas is exhausted by mechanical means it becomes necessary to employ a regulator (Fig. 4) in order to equalise the pressure and production. The gas enters through o o and leaves by the pipe N N', which is conical, and contains a conical plug P regulated by the balance weight outside; so that when the production of gas diminishes the cylinder M falls and permits the gas to escape more freely.

The gas now passes through F (Fig. 5) to a series of pipes *r r r*, called condensers, where the greater portion of the tar, gas, water, &c. are separated by the action of the cold air. The condensers are in the form of an inverted ∩, and the lower ends are fixed in

metal boxes R R R, from whence the products of condensation flow off by means of luted syphons as they are formed into a main pipe $v\,v'$.

Various methods are adopted for purifying the gas after it leaves the condensers, but that most generally followed is shown in Fig. 6 : large metal boxess, filled with shelves, are covered lightly with hydrate of lime, through which the gas passes. In order to keep up a continuous supply of pure gas, a cylinder x is placed so as to serve as a reservoir, and being divided into five compartments, the gas is withdrawn from any of the purifiers which require fresh lime. Where two such cylinders exist, the gas is directed to either, in case of repairs, by the valves $v\,v'$.

The gas now enters the gasometer z z through a valve at y, regulated by a lever outside, and leaves it in a similar manner.

The gasometer communicates with the apparatus by a pipe $F^2\,F^3$, which is rendered flexible by joints made tight by means of stuffing boxes. This pipe, and that marked $F^4\,F^5$, also serve to suspend the gasometer.

The gas passes off underground and is measured by a large meter, Fig. 8, by means of the valve at a, which communicates its indications by the machinery at e to the hands of the dial plate. The pressure of the distribution is also measured by a manometer at e. The illuminating power can also be tested by means of the receiver at d.

We will now describe in more detail the several parts of the apparatus used in the process.

The vessels used for the distillation of coal are called retorts.

Those first employed by Murdoch were circular tubes with diameters one-third their length. They were placed upright in the fire, and a pipe was attached to the upper end for carrying away the volatile products. A pyramidal form was afterwards tried, with an aperture at the side near the bottom for extracting the coke, but with this form the heat did not penetrate sufficiently into the body of the coal. Cylindrical retorts of cast iron, about 7 feet long and 1 foot in diameter, placed horizontally over the furnace, and supported at the back or closed end by a stout peg or projection v, Fig. 358, were ultimately adopted, and continued to be generally used for a length of time.

The flaws which often occur in cast iron, arising from particles of clay, air-bubbles, &c., render it necessary that each retort should be tested, before being used, with reference to its impermeability to

gas. The conducting pipes or mains require testing in the same manner, and this is usually done by forcing water into them under a pressure of 1½ to 2 atmospheres, or air at the same pressure is even better: the tubes being then placed in water, the escape of the air, if such should occur, can be observed. The retorts were formerly not cast in one piece; the body, which is exposed to the fire, becoming from time to time useless, required to be changed, while the neck or mouth-piece remained uninjured. The mouth-piece and body of the retort were connected by bolts and flanges, the former being left open in front for the convenience of charging and discharging, and furnished with an easily fitted lid *d*, Fig. 350, which was fixed by means of the screw *w* and the hold-fast *v*. The latter, by means of a hinge at one end and a peg at the other, could be turned back, or firmly pressed against the mouth of the retort *a a*. The mouth of the retort and the lid were

FIG. 350.

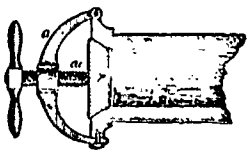
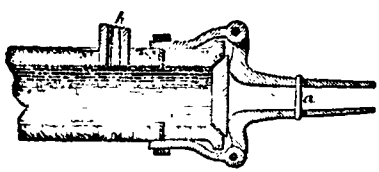


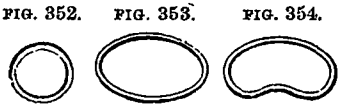
FIG. 351.



ground conically like a valve, and by covering the two inclined surfaces with clay, and screwing up the lid, an air-tight joint was made in a few moments. Two bent levers, Fig. 351, were sometimes used, which, when the ring *a* is forced up, press with their shoulders against the lid. A wide ascension-tube *h*, Fig. 351, was either cast to the mouth-piece or attached to it by a socket-joint. The mode of closing the retorts now generally practised is shown at Fig. 3, Plate III.

The best form of retort would be that by which the coal could be most completely brought into contact with the red-hot sides; and at the suggestion of Prechtl, the original circular form of retort, Fig. 352, was soon superseded by the elliptical, Fig. 353, which has been further improved by bending in the lower surface, Fig. 354. With the same length of 6.5 feet exposed to the fire, 150 lbs. of coal, when they only half fill the retort, will cover, in the round retort, a red-hot surface of 10 inches in width, while in the oval shape they cover a surface of nearly 12 inches. The layer of

FIG. 352. FIG. 353. FIG. 354.



coal is only 4 inches thick in a retort of the latter form, and is about one-third nearer the top than in the circular form. The advantage thus obtained is said to reduce the time required for the distillation nearly one-half.

Flat-bottomed iron retorts, in the shape of a D, are more commonly used now than any others, and the dimensions of these vary in different places. Two sizes are chiefly used in this country,—the small London D, about 12½ inches wide by 12½ inches deep in the clear, varying in length from 6 to 9 feet; and the York D, from 20 to 30 inches wide, 9 to 14 inches high, and of unequal length. Rectangular retorts, with the roof arched, are sometimes employed. The capacities of the retorts are adapted for charges varying from 120 to 200 lbs., and this quantity is generally worked off in from four to eight, on the average six hours; so that a retort containing 1¼ cwt. of coal will carbonise 6 cwt. in the twenty-four hours. The back of the retort is generally square, but a curved form is better, as this part being exposed to the strongest heat of the furnace, is liable to be rapidly burnt away. By heaping up a portion of the charge at the far end of the retort, the action of the heat upon the iron is reduced. The method commonly adopted for fixing the lid and the ascension-pipe is shown in Fig. 350, where the retort has an elliptical form, and the lid extends over the edge of the retort mouth, clay mixed with refuse lime from the purifier being employed as cement. In place of the screw, a lever and weight are sometimes employed for keeping the lid in its position.

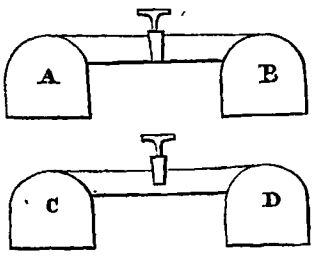
Iron retorts of double the ordinary length, and of the D shape, with a lid and ascension-pipe at each end, were proposed long since by Mr. Lowe, and worked or charged at each end alternately, the gas and tar from the fresh charge being allowed to escape over the hot half-carbonised charge at the other end of the retort. This reciprocating action was obtained by causing the pipes delivering the gas to dip unequally into the liquid in the hydraulic main, and using a cup-valve to close, when required, the end of the pipe least immersed. The gas could thus be allowed to escape at either end of the retort, and much tar became converted into gas by passing over the heated coke of the partially-decomposed charge.

More gas is produced by this system of working, and at a less cost of material and setting; but a portion of the heavy carbo-

hydrogen is no doubt destroyed by the greater contact with heated surfaces.

A modification of Mr. Lowe's reciprocating retort has been worked for some time at the Pancras station of the Imperial Gas Company. The retorts, shown in section at Fig. 355, are set four in an oven or bench, two below and two above; those on the same level being connected with each other by a cross pipe, in which is a valve, so that the two retorts form only one distilling vessel when the valve is open, but can be worked separately when the valve is closed. Each retort is furnished with an ascension-pipe and cup-valve, so that the gaseous products from the one can be carried to the hydraulic main through the other retort and ascension-pipe, by opening the valve in the communicating pipe and closing the cup-valve of the retort from which the gas is generated.

FIG. 355.



In working a pair of these retorts—for instance, A B—the gas from the charge in A is allowed to pass through the half-exhausted coal in B, until half the period for fully exhausting the charge has expired: the retort B is then re-charged, and the gas allowed to pass for the same time over the hot coal in A.

Iron retorts 19 feet 6 inches long, with one ascension-pipe only, but open so as to admit of being charged at both ends, are coming more generally into use, in consequence of the greater economy in their prime cost, in setting, and in the fuel required for heating them. We shall have to allude again to these in connection with the modes of setting now adopted.

Mr. Brunton employed for many years, at West Bromwich, an iron retort in the form of a section of a cone, the smaller end being 15 inches in diameter, and the larger 21 inches. The upper surface being placed horizontally in the furnace, an inclination of six inches was obtained on the lower, the object of which is to afford a more ready discharge of the coke, and allow for the increase of bulk which it underwent in charring. An ascension-pipe and also a discharge-pipe opening below the surface of water were attached to the lower wider end of the retort, where was also a door for inspecting the interior. To the front and narrow end a mouthpiece was attached, into which a hopper

discharged about 20 to 28 lbs. of coal every hour, the aperture between the hopper and retort being closed after the admission of each charge by a slide. A piston also worked through a stuffing box in the mouthpiece in such a manner as to force, by means of a screw, the fresh coal forward into the retort, and at the same time discharge a proportional quantity of the coke at the farther end. The fresh coal was thus distilled in the front part of the retort, and the gas and tar were obliged to traverse the coke at the remoter parts before arriving at the ascension-pipe. So large a proportion of the tar was thus converted into gas that the inventor of the method states the ultimate yield of condensible products to be 50 per cent below that obtained by the ordinary method of working.

A totally different method of conducting the distillation of coal, and eminently calculated in principle, not only to improve the quality, but also to increase the quantity of the gas, is that in which an endless chain or web is moved by machinery, and adapted to convey the coal slowly through the heated chamber, where it is distilled.

This arrangement is known as the revolving web retort, the upper part of which consists of a flat-bottomed vessel of boiler plate, 7 feet long, 26 inches wide, with an arched top, giving a depth of 7 inches in the middle and 3 inches at the sides; two six-sided drums, with a periphery equal to the length of the retort, are placed one at each end, and moved by a shaft extending the whole length of the bench of retorts. These drums support and give motion to the endless web or chain, consisting of plates of iron 2 feet long by 14 inches wide, connected together by links of round iron. The coal, broken into pieces of the size of a bean, is placed in a hopper above each retort, capable of containing a twenty-four hour charge, and made air-tight by a lid and water joint: by means of a feeder, also moved by a shaft common to an entire set of retorts, a supply of coal is delivered to each plate of the web as it passes below the feeder, covering it to the depth of three-eighths of an inch. The motion of the drums is so regulated that the coal is about fifteen minutes in passing from the front to the back of the retort, where, having been converted into coke, it is precipitated from the web, and falls into a descending-pipe opening below the surface of water, while the web returns through a chamber below, separated from the upper carbonising space by a mass of solid brickwork, to

receive a fresh charge. The stand-pipe for conducting the gas to the hydraulic main is at the far end of the retort. The whole operation is here carried on mechanically by machinery, and a very large surface of coal is exposed for a very short time to the full intensity of the heat in the retort, every pound of coal being spread over a surface of nearly 100 square inches. Each retort is said to yield 5.36 cubic feet of gas for every pound of Wall's-end coal, or at the rate of 12,000 cubic feet per ton; while the specific gravity of the gas is 0.490. Each retort will carbonise 18 cwt. of coke in 24 hours,—a quantity nearly double that afforded by the ordinary retort, while the coke is said to be increased 75 per cent,—a statement which can only have reference to bulk.

The first cost of erecting these retorts, with the machinery for working them, is considerably greater than for the same number of the ordinary construction; but the working expenses are diminished, and the cost of repairs is said to be less. They have not, however, been sufficiently tested in a practical manner to induce the managers of gas-works to adopt them generally.

The destruction of iron retorts in the process of gas manufacture is very rapid,—which may be attributed to several distinct causes. Besides the direct action of the heated gases of the furnace oxidising and gradually burning away the metal, the sulphur contained in the coal acting upon the outside of the retort, converts it partially into sulphuret of iron, which is comparatively easily fused, and melts away. In the interior the heavy hydrocarbons and tar vapours arising from the coal, coming in contact with the red-hot sides of the retort, are decomposed, and deposit carbon, in the form of graphite, all over the inner surface, which becomes encrusted to a depth of one or two inches. This deposit on the side nearest the retort consists of a carburet of iron, containing 1.72 per cent of iron, and the different layers vary in specific gravity from 1.7 to 2.3: it is exceedingly hard, striking fire with steel, and is capable of taking a fine polish. This substance is a very bad conductor of heat, and prevents the coal in the centre of the retort being rapidly heated and distilled; thus causing an increased expenditure of fuel, and a more rapid destruction of the retorts; while its removal, which is sometimes effected by leaving the doors open, when the carbon is burned away by the oxygen of the air, is always attended with a considerable

loss of time and corresponding oxidation of the iron of the retorts.

These obvious inconveniences attending the distillation in iron retorts led Grafton, in the year 1820, to propose and patent the use of clay as a material for their construction. They were first made in the form of a square; but the shape shown in Fig. 356 soon superseded the square, and pieces of this sectional shape, 4 to 5 feet wide and 12 to 18 inches high, were joined together with clay so as to form an oven, or distilling vessel, of 7 feet in length, and capable of distilling 7 cwt. of coal in six hours, or five times as much as the small iron D-shaped retorts. Each of these retorts, connected with an iron mouthpiece D, was at first placed in a separate furnace, as shown in Fig. 357, supported by the pillars G G, but they are now employed of very different shapes, round, oval, and D-shaped, several together in one bench or furnace, and often associated with iron, as will be described below.

FIG. 356.

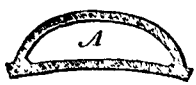
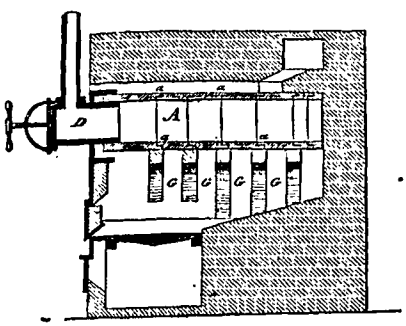


FIG. 357.



The relative merits of clay and iron retorts still form matter of controversy among gas-engineers. In Scotland, where cannel coal is almost exclusively employed in the manufacture of gas, clay retorts are in very general use; and in England they are gradually superseding iron retorts, or are used in conjunction with them.

The grounds on which clay are preferred before iron retorts depend chiefly upon two circumstances:—

1. The production of a larger quantity of gas of equal, or even superior quality, from a given amount of coal.
2. Less prime cost, greater durability, and consequently less outlay for wear and tear.

The larger production of gas in clay retorts appears pretty generally admitted, although some experimenters have not found it verified. Thus—

One writer in the "Journal of Gas Lighting" working 15 cwts. of coal in nine retorts under a pressure of 11 inches of water, obtained in—

Iron retorts 9064 cubic feet per ton = 303.58 lbs per ton.
Clay retorts 8000 „ „ = 261.40 lbs „

giving 1064 cubic feet, or 42.14 lbs. per ton more gas from the iron than the clay retorts; while another, computing the average comparative result of two years' working with iron and clay retorts in an establishment which produced 50,000,000 cubic feet annually, gives—

Gas per ton of coal and cannel in iron retorts 9,500 cubic feet.
„ „ „ clay „ 11,210 „

and as the result of eight weeks' working with *new* clay retorts the following:—

Quantity of Gas produced during eight weeks.	Number of Retorts in action.	Quantity of Cannel carbonised during eight weeks.			Average Quantity of Gas produced per ton of Cannel.
		Tons.	Cwt.	Qrs.	
2,453,400 cubic feet.	Partly 10 and 15 clay retorts.	219	2	2	11,196 cubic feet.

Clay retorts are usually worked at a higher temperature than iron, and the cause of the larger quantity of gas produced is generally attributed to the decomposition of a portion of the tar at this higher temperature, which, when iron retorts are used, passes into the condenser.

The greater bulk of gas may perhaps be explained, as Dr. Fyfe observes, by the olefiant acquiring hydrogen, or, what amounts to the same thing, by more light carburetted hydrogen being produced with the same amount of carbon, which, in adding to the volume, would diminish the illuminating power of the gas. This may possibly be the case, although no proof has been furnished that the gas from clay retorts is inferior in illuminating power to that of iron retorts.

The relative cost of the retorts is most conveniently expressed by the quantity of gas they will produce. The duration of iron retorts is estimated by Mr. Barlow as equivalent to the production of 700,000 cubic feet of gas. Clay retorts, made in a single piece by Cowen, of Newcastle, are said to produce as much as 1,800,000 cubic feet of gas, and continue in uninterrupted action for seventeen months and longer. Much, however, must

depend upon the quality of the clay, and the care in the manufacture; and to these sources must be attributed the great diversity of opinion on the relative merits of clay and iron. The writer in the "Journal of Gas Lighting" who advanced the first of the foregoing comparisons between clay and iron retorts, estimates the cost of maintaining

Iron retorts at 3.41 pence per 1000 cubic feet of gas.
Clay „ 2.26 „ „ „

showing an economy in the use of clay retorts of 1.15 pence per 1000 cubic feet of gas produced. Another writer in the same journal estimates the expense of clay retorts, as the average of nine years' working, at 1.41 pence per 1000 cubic feet.

The objections raised to the employment of clay retorts are:—

1. The higher temperature at which they are advantageously worked involves a greater expenditure of fuel.
2. A greater amount of carbonaceous deposit is formed on the interior, which is produced by the decomposition of olefiant gas; and the quality of the illuminating mixture is consequently impaired.
3. The porous nature of the material allows much gas to be lost by leakage.
4. The brittle nature of clay renders it more liable to fracture.

Clay retorts are worked at an incipient white heat, while the best results are obtained with iron retorts at a cherry-red heat. The quantity of fuel required to produce an equal quantity of gas has been estimated—

For clay retorts, at $3\frac{1}{2}$ cwt. of coke per ton of coal carbonised.
„ iron „ $2\frac{1}{2}$ „ „ „

This is equivalent for clay retorts to about one-fourth of the coke produced, and for iron to about one-fifth.

If this estimate be correct, the value of the coke at the place of production must determine in a great measure the relative economy of the retorts.

In small gas-works, where a very variable quantity of gas is required at different seasons of the year, and there is much loss of heat from the small number of retorts employed in a single furnace, the consumption of coke for fuel amounts to from one-third to one-half the total quantity produced, and very little difference is observed in this quantity, whether iron or clay retorts are used.

Clay retorts, however, afford a larger quantity of gas in a shorter time, and fewer furnaces require to be heated. For this reason they will probably be found more economical under such circumstances.

The second objection has reference rather to the temperature employed than to the material of the retort; and the quantity of carbonaceous deposit is very much influenced by the amount of pressure which the gas must overcome in escaping. Olefiant gas, when brought into contact with surfaces at a red heat, deposits carbon, and becomes converted into an equal volume of light carburetted hydrogen. The higher the temperature, and the longer the gas is exposed to it, the more complete is the decomposition.

Dr. Fyfe estimates that for every 225 grains of carbon deposited, 1 cubic foot of olefiant gas may be decomposed; and taking 16 lbs. of deposit as the minimum for a clay retort per month, the amount of olefiant gas decomposed would be 500 cubic feet, which, however, is probably much less than the quantity actually destroyed in practice. The quantity of gas produced, the relative quality of the gas, and the amount of coke remaining from each kind of retort, must be accurately tested before the comparative merits can be definitively settled. The deposit of carbon may be considerably lessened, as also the amount of leakage through the pores of the clay, by removing the pressure from the retorts with an exhausting apparatus, which pumps out the gas as it is produced.

The porosity of clay retorts, on first using them, is admitted by all; some affirm that the pores become stopped after twenty-four hours' use, while others state that months must elapse. Much must here depend upon the character of the clay employed in their manufacture, and also upon the treatment they have been submitted to in burning. More, however, depends upon the pressure exerted upon the retort. Thus, in a direct experiment in which gas was admitted into closed empty retorts, it was found that iron retorts which had been in use six months, and were in good condition, leaked 4 feet per hour under a pressure of 9 inches of water; and clay retorts, which had been in use during one month, leaked 21 feet during the same time.

Supposing a single retort to carbonise one ton of coal in sixty hours, the leakage under this pressure would amount

In iron to 400 cubic feet per ton of coal.
In clay to 1260 „ „

The leakage in clay retorts under 2-inch pressure was, however, reduced to 5 feet per hour,—a remarkable fact, says the observer, if true, as the passage of gas under pressure through fine apertures is known to be directly as the square root of the pressure; while in this instance it is directly as the pressure. The explanation of this must probably be sought from the law of the transpiration of gases, or their passage through capillary tubes, established by Graham. According to this law, the denser or more compressed the gas, the more quickly it is transpired; and 9 : 2 :: 21 : 4.7, or nearly 5, as observed in the experiment.

When the pores of the clay become choked with the carbonaceous deposit, the leakage is stopped, and by diminishing the pressure the same amount of gas may be obtained as from iron retorts.

The last objection, or the liability of clay retorts to fracture, has not much weight, since improved modes of setting and handling them in the furnace have been introduced; and chance cracks may be completely stopped or rendered air-tight with clay.

Retorts in the form of an oven, 3 feet 2 inches wide, 7 feet long, and 14 inches high, constructed of Newcastle fire-tiles and Stourbridge fire-brick, have been used for many years in the west of England, where they were first introduced by Spinney. They are adapted for distilling 5 or 6 cwt. of coal at a time, and require twelve hours for working off the charge. About two-thirds of the coke produced is used to heat these retorts; but less labour is required in working them, and they have been known to last for ten or eleven years without being taken down, and with only a small annual expense for repairs. The ascension-pipes are closed by a cup-valve when the retorts are being charged, an arrangement which allows them to be worked at a pressure of only 4 inches of water. A superior coke, amounting to 15 cwt. per ton of coal carbonised, is said to be obtained, and about 9,000 cubic feet of gas from Welsh coal, or from 10,000 to 12,000 from Newcastle coal.

The fire-brick retorts patented by Clift are built with bricks especially made for the purpose, each brick being rebated an inch deep at two of its joints, and having a dowelling triangular groove at the other two joints, which, being filled by a tongue of hard fire-clay, add much to the strength of the retort. The retorts are 20 feet long, of the D shape, set two or three in a bench, and charged and fired at each end. According to the statements of

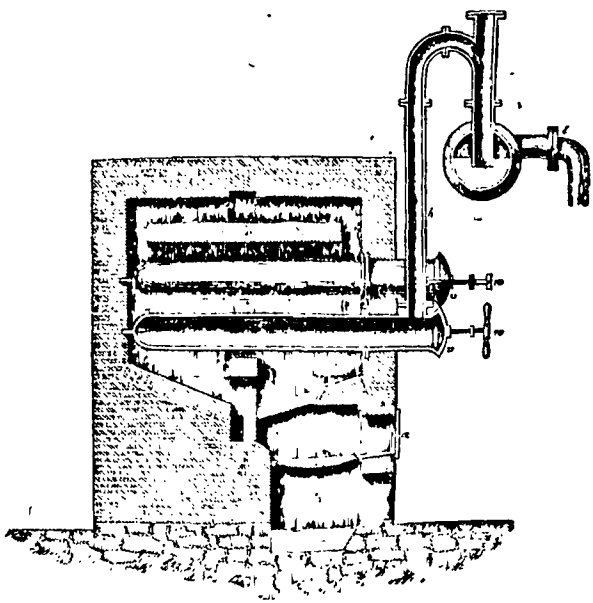
the inventor, these retorts continue to work for ten years and more, with an expense of only twenty shillings per annum per bench for repairs, a sum infinitely below the cost of wear and tear on iron retorts. The retorts leak for about twenty-four hours after they have been fired, but then become tight, even under a pressure of 10 or 12 inches of water. A bench of three retorts is calculated to produce 20,000 feet of gas in twenty-four hours. Fire-brick retorts are used in Birmingham, Coventry, and in several midland towns of England.

In Liverpool, Mr. King has introduced wrought-iron retorts, constructed of boiler-plate, protected by fire-tiles on the bottom from the direct action of the fire. These retorts are of large dimensions, so as to present an extensive heating surface, and afford at high heats a large production of gas, but soon become misshapen by the heat, and speedily burnt out.

A patent has recently been secured by the Messrs. Evans for so glazing the inside of retorts as to prevent the deposit of carbon.

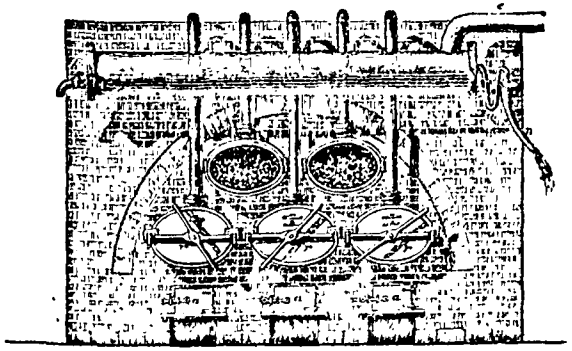
The Furnace, Oven, or Bench.—Fig. 358 shows the arrangement

FIG. 358.



and position in which the retorts were formerly placed in the furnace. Fig. 359 is a front view of the same. Three fires were

FIG. 359.

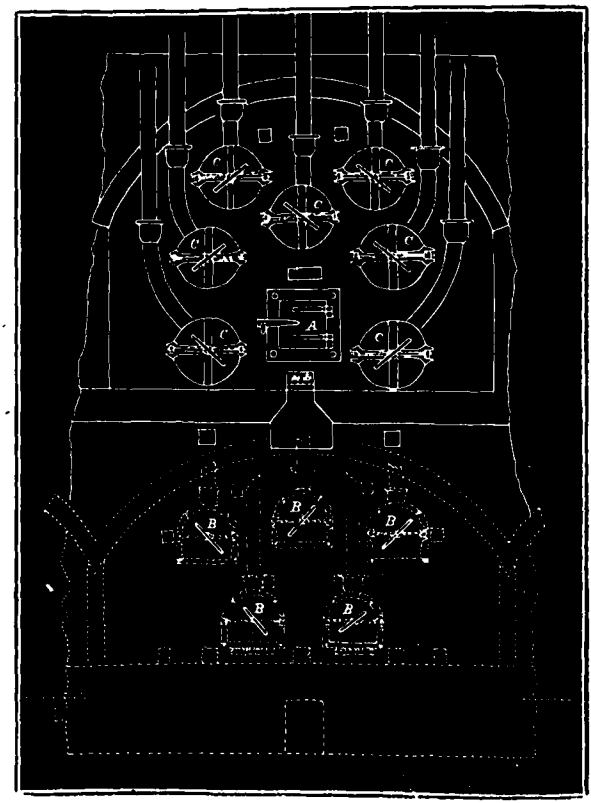


employed for heating five retorts set in the form of a pyramid. The doors to the fires are shown at *a*, the grate at *c*, and the ash-pits at *b*, with a well *e* for water, or used occasionally for drying lime from the purifiers; three arches *d* passed transversely over each fire and divided the flame; *c c* was the large arch over-spreading the retorts *r r*, against which the flame was broken, before escaping at the side. The conducting or stand-pipes dipped into the hydraulic main at *i* in the manner described before. A most rapid destruction of the retorts, and wasteful expenditure of fuel, attended this method of setting, and attempts were made to protect the iron from the direct action of the fire by enclosing them with grounds made of fire-brick; but this very expensive expedient was not found to fulfil the object proposed, as wherever the clay came into contact with the iron, the latter became oxidised, combined with the ingredients of the clay, and the compound thus formed was more fusible than the iron itself; the retorts were thus more speedily destroyed than when unprotected, and the brick-work supporting them shared the same fate. Clay retorts were substituted to obviate these defects, and the mode of setting these has been already described. The amount of fuel required for heating these being, however, considered extravagant, and a large proportion of the heat passing uselessly into the chimney, Mr. Croll was induced to construct furnaces in which both clay and iron retorts could be heated from the same fire, the clay retorts being arranged immediately above the flame, so as to receive the most intense

heat, while the waste heat was conducted in a downward direction upon a set of iron retorts.

This arrangement is shewn in Figs. 360, 361, and 362. Fig. 360

FIG. 360.

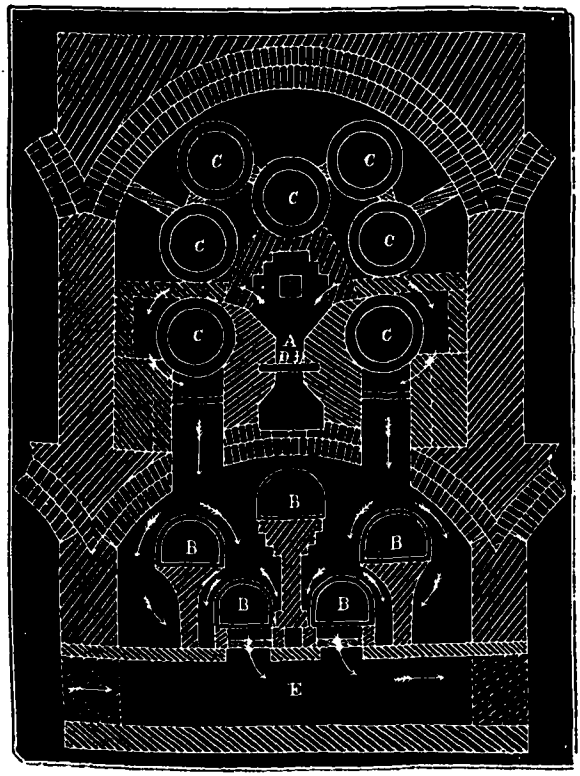


is a front view, Fig. 361 a cross section, and Fig. 362 a longitudinal section of ovens and retorts, as constructed upon the first plan of Mr. Croll.

The oven is constructed to suit the size of the retorts, and when five iron retorts *B B*, Fig. 360, are employed, three are set towards the top of the oven, each upon 3 brick pillars, and the two lower ones upon flues 6 inches high, running the whole length of the retorts, (compare cross section, Fig. 361), and open at the back. Another oven is placed above, in which seven retorts of fire-clay *CCC* are fixed, Fig. 360: five of these are above the furnace

or firing *A*, and one on each side of it. The furnace *A*, is 3 feet long, and 1 foot 6 inches wide, tapering to 7 inches at the level of the two bars *D D*. *F*, Fig. 362, is a trough containing water for cooling the bars, &c. The fuel in this furnace assumes the

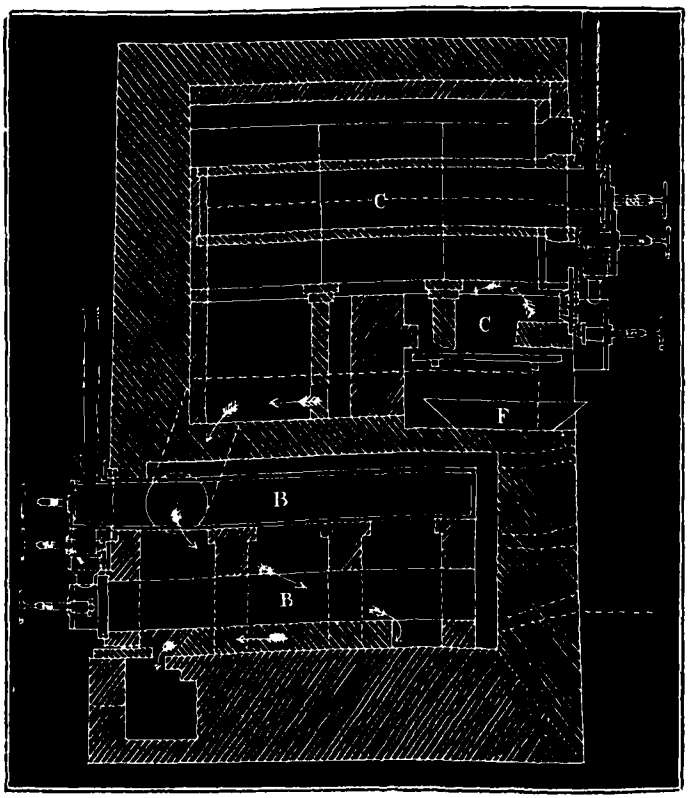
FIG. 361.



form of a wedge, the object of which will be afterwards explained. Coke is the fuel used, and it will be seen by referring to the direction of the arrows in the cross section, Fig. 360, that the flame proceeds from the furnace over the two lower clay retorts, and thence (v. longitudinal section, Fig. 362), passes along their bottoms to the further end, where it descends through openings in the arch to the oven below, and comes into contact with the front of the upper iron retorts; when they are arranged, as represented in Fig. 362, with their mouths on the opposite side of the retort stack, the heat then traverses obliquely to the bottom of the oven at the back end,

where it passes underneath the two lower iron retorts, and is conveyed to their front, descending at last into the main flue *E*, Fig. 361, which runs transversely with the settings, and thence to the chimney, which is only about 3 feet above the ridge of the retort house. It

FIG. 362.



is found, that the five upper clay retorts are heated quite sufficiently by the radiated heat from the furnace, although the flame is conducted below them to the lower oven. The clay retorts in this arrangement are heated by the most intense part of the flame, which, when it reaches the iron retorts below, is so moderated that no casing of clay is needed, nor is the brick-work in contact with the iron fluxed or melted away. The furnace *A* is wedge-shaped, that the fuel may sink gradually as it consumes, and that the same quantity of air may always be admitted, which is not the case

when the fuel burns irregularly in oven fires of the ordinary description.

In the gas-works at Tottenham, where Mr. Croll's plans were first carried out under the superintendence of Mr. Anderson, the retorts were charged with 260 lbs. of coal, which quantity could be raised, in case of necessity, to 300 lbs., and this was worked off in 4½ hours. The clay retorts are said to last the usual time, but the iron retorts in the lower oven last very much longer than ten months, which was the average duration upon the old plan; and this is also the case with the brick-work upon which they are supported. A very considerable saving of fuel is also effected by the use of the arrangement described above, only 24 per cent of the coke produced being consumed in heating the furnace.

A still greater number of retorts, and those of larger dimensions, are now set in one furnace: thus, at the Gas-works of the Great Central Company at Bow Common, 13 retorts, of double the ordinary size, are heated by two fires. Six clay retorts *a a a*, two of an oval shape, and 4 round, are placed in the upper oven (Fig. 4, Plate II.), and receive the direct flame of the furnace at *b*, which is then conducted by the flues *l l* into the lower oven, where it heats seven smaller iron retorts before escaping by an underground flue to the chimney. The clay retorts are 18 feet in length from the face of the brick-work setting, and are charged and discharged at both ends. The iron retorts are 19 feet 6 inches long, including the mouth-piece with which they are cast in one piece. Each clay retort is charged every four hours, producing in the 24 hours 8,500 cubic feet of gas; the iron retorts are charged every six hours. The total make of gas in the works from 12 settings, occupying a space of 18 feet in width by 124 feet in length, is 900,000 cubic feet per day, which can be increased to 1,200,000 cubic feet if necessary.

The average consumption of fuel is estimated at from 12 to 15 per cent of the coke made, which shows a very great economy in favour of this mode of working. Such is the proximity of the retorts in the ovens, that there is not room on one side of the erection for the ascension pipes *d d*, and these are distributed part on the one side, and part in the other, descending into the mains *e e*, supported by the hollow columns *f f*, which are tied together by the rods *g* passing over the ovens. These columns also support the girders upon which the platform is erected for working the upper ovens. The fire-places *b* have only one fire bar of round iron, and to prevent the two fires drawing into each other, a partition wall *j*

extends completely across the arch, and separates the furnaces from each other.

Distillation.—The process of distillation hardly requires further notice; the coal is generally thrown with shovels into the glowing retorts, spread about, and the lid immediately screwed on. Wrought iron scoops, 7 to 9 feet long and 10 or 12 inches diameter, are now often used for charging the retorts, which contain an entire charge of coal, and require three men to work them. Being previously filled with coal, a man on each side of the scoop lifts the end of it into the mouth of the retort, while a third, who holds the rod and handle attached to the other end of the scoop, pushes it forward to the end of the retort; the contents are then turned out by inverting the scoop, which is quickly withdrawn, while another workman instantly applies the lid, coated with cement at the edges, and screws it tightly to the mouth. Much less time is thus consumed in charging, and the retorts are not so long exposed to the cooling action of the air.

The process of distillation requires four, five, six, or eight hours, according to the nature of the coal, and the shape of the retort; the lid is then quickly unscrewed, the gas contained in the retort ignited before it forms an explosive mixture with the air, the glowing coke raked into iron barrels, where water is thrown upon it, and the retort re-charged as quickly as possible. In large works the iron barrows are placed upon a railway in front of the retorts, so as to be rapidly removed. The portion of coke which is used as fuel should be employed as it is taken red-hot from the retorts, in which case all the heat required to raise it to redness is economised, and according to Croll, who first adopted the practice, a saving of 10 per cent of fuel is effected.

From the ordinary arrangement of the retorts, and the process of distillation carried on in them, the favourable circumstances under which the gas is at first evolved do not continue, and the last portions of gas are never so rich in illuminating matter as the first. The revolving web retort already described, would, if practicable, certainly tend to diminish this inequality; other plans have also been suggested with the same view. Heginbotham proposed that the retorts should be furnished with a moveable screw throughout their whole length, the worm of which worked against the inner side of the retort. This plan is very similar to that now adopted for the distillation of saw-dust, spent-tan, &c., and described at pages 349-351. Small coal is constantly introduced

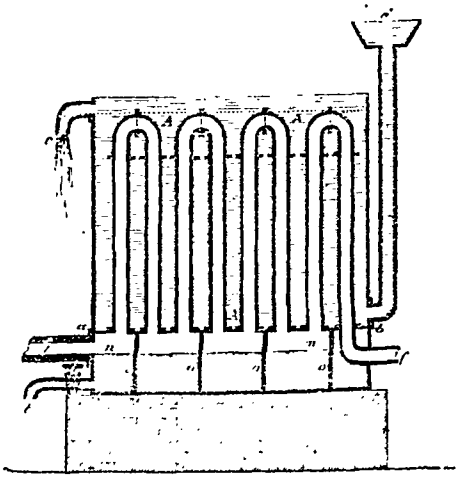
into the retort at one end, and slowly propelled by the screw through the red-hot chamber, to be expelled at the opposite end, where it falls, as coke, through a funnel into a closed water-tank. The excessive evolution of hydrogen towards the end of the operation does not occur with this apparatus, but we are not aware that it has ever been tried on a large scale, and the valueless form of the coke is probably a serious objection to its adoption.

The stand pipes which convey the gas from the retorts are usually about 4 inches in diameter, and rise to a height of 4 or 5 feet above the hydraulic main, where a semi-circular bridge or saddle-pipe connects them with the dip-pipes, which enter the liquid of the main. The latter are therefore 4 or 5 feet in length, and a cap is usually fitted to the upper extremity of both stand and dip-pipes for the purpose of cleaning. The hydraulic main itself is a large pipe of cast or wrought iron, the latter material being now generally preferred for its lightness, from 12 to 18 inches diameter, and sometimes flattened on the top. Into this pipe, which is placed in a perfectly horizontal position, and half filled with the liquid products of the distillation, the dip-pipes are secured in a perfectly air-tight manner, with their mouths dipping 3 or 4 inches below the level of the liquid. A perfectly secure joint is thus effected, the level of the liquid in the main being so adjusted to the height of the dip-pipes and the pressure of the gas that it can never be forced up any one of the pipes sufficiently to expose the mouth of the pipe for the admission of air when the retort is open during the operation of charging or discharging. The exact position of the main is immaterial; it may be set in the brick-work over the ovens, supported by columns, or placed below the floor of the retort-house. One pipe in the upper part of the main conducts away the gas as it bubbles through the liquid to the condensers, while another, fixed just above the level of the liquid in the main, with its other end dipping into the liquid in the tar-well, carries away the liquid products.

The Condenser.—The hot gas issuing from the hydraulic main, laden with condensible tar vapour, which, if allowed to condense in distant parts of the apparatus, might stop up the pipes and valves, is conducted at once to the *coolers*, or *condensers*, which are variously constructed, but have all the common object of cooling the gas. The old condenser, Fig. 363, consisted of a large iron chest, with a false bottom *a b*, the upper part of which *A* was filled with water, and contained a series of pipes, connected together

by saddle-joints, passing air- and water-tight through *a b*. The lower part was partitioned off by four plates *o o o* into as many distinct compartments, in which the fluid products collected until they attained the level *n n*, when they escaped by the tube *l*. Cold water was allowed to flow into the apparatus through *d*, and the warm water discharged at *e*, the gas itself passing on through *f* to the purifiers; the pipe *t* is used for drawing off the tar. Other condensers are constructed with horizontal pipes, surrounded by water, which are still often used; or a tank, placed at a high level, may be employed to supply an uninterrupted shower of water upon a series of upright pipes through which the gas is passing. Upright pipes, 6 or 8 inches in diameter, and from 20 to 30 feet high, connected together two and two above, and open to vessels in communication with the tar-well below, are, however, most commonly used, and one pipe of 20 feet high is calculated as necessary for every 20,000 feet of gas passing in the twenty-four hours. Condensers of this description are shown in the drawing, Plate I. The air acting on the exterior of the pipes here causes the condensation.

FIG. 363.



The relative effect of water and air as condensing agents for gases has been studied by Peclet and others, and the following table exhibits their results:—

Excess of temperature in the gas	Quantity of heat lost by a square unit of exterior pipe surface.	
	When radiating in open air.	When plunged into water.
For an excess of 10°	8	88
" " 20°	18	266
" " 30°	29	5353
" " 40°	40	8944
" " 50°	53	13437

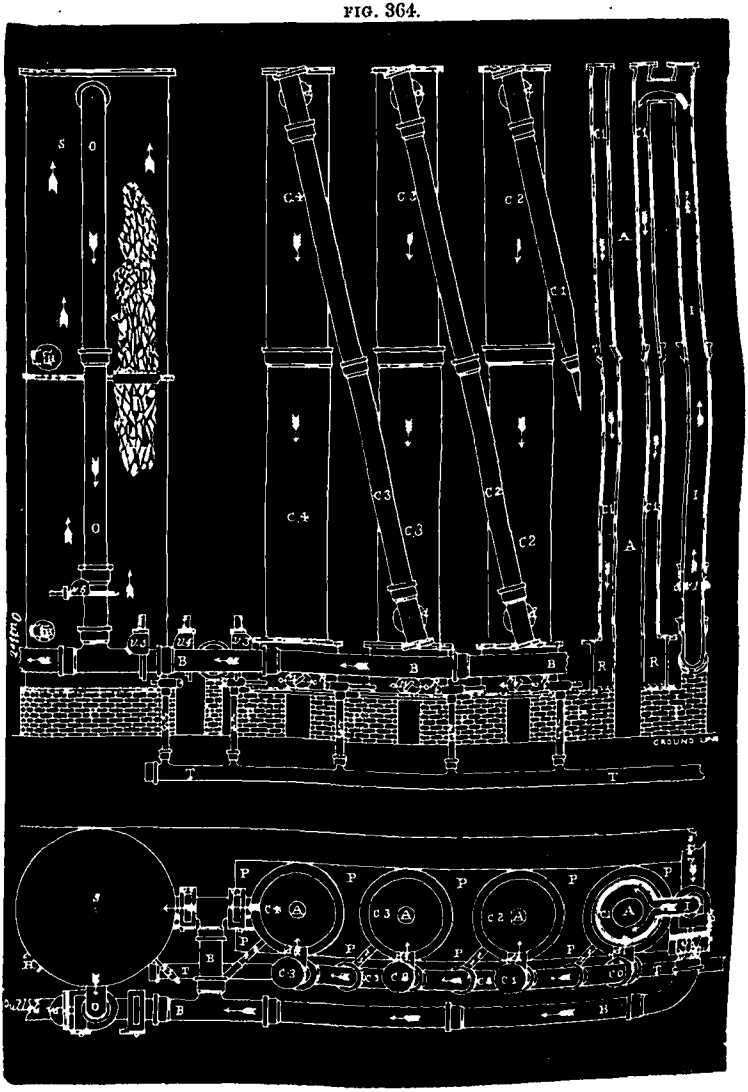
It will be seen from this table that when the difference of temperature between the gas and the water employed for condensation is only 10°, the effect of the water is considerably greater than that of air, where the difference of temperature is five times as great.

Washers or vessels containing water through which the gas is obliged to force a passage have sometimes been employed to assist the condensers. These were placed between the retorts and condensers, but most experienced engineers being of opinion that all contact with water is injurious to the quality of the gas, and the passage of the gas through the water in these vessels increasing the pressure upon the retorts, they are now seldom used. Condensation may be, and probably is, carried too far; part of the luminous hydrocarbon vapours being condensed with the tar. From the investigations of Mr. Lewis Thompson, it appears that the hydrocarbon vapours contained in Newcastle coal gas at 60°, having a specific gravity of 3.2, are condensed at a higher temperature than those existing in Boghead Cannel and Wigan Cannel gas, having specific gravities of 1.21 and 1.77 respectively, so that the latter may be cooled to a greater extent than the former, without injury to the illuminating power of the gas. It thus appears that the process of condensation, upon which very little attention is often bestowed in gas-works, should be under control, and the extent to which it is carried modified according to the nature of the gas and the temperature of the external air. Common coal-gas experiences a rapid diminution of illuminating power when cooled below 50° F. although cannel gas will bear a lower temperature unimpaired. In the ordinary condensers, no change is made to suit the varying conditions of the atmosphere, nor could this be conveniently done as they are at present constructed. Mr. Kirkham very much increased the power of the condenser, by causing the gas to pass up and down alternately through a space of 5 or 6 inches, included between two concentric pipes, through the interior of which the air could circulate. Mr. Wright's condenser is an improvement upon Kirkham's, the gas being obliged to pass in a contrary direction to the current of air, through the ventilating columns, and not alternately up and down, while, by means of a cap which can be fixed upon the ventilating column and removed at will, the current of air can be regulated, and the condensation kept under control.

Fig. 364 shows a section, elevation, and plan of Mr. Wright's condenser. The external column c^1 is 3 feet in diameter and 18

feet high; the internal column A is 2 feet in diameter, the ring of gas between the two being 5½ inches wide, with an area nearly equal

FIG. 364.



to that of a pipe 26 inches diameter. The transfer of the gas from the base of one column to the top of the next, is effected by 12 inch socket pipes. Covers are supplied for the inner ventilating pipes,

which enable the current of air to be regulated according to the temperature. The number of the columns required will depend upon the quantity of gas passing; but, as an illustration of their effective value, an experimental result is given below, in which eight columns were used :—

The temperature of the air being 55° F., rain falling, and the covers being removed from the ventilating pipes, with 12,400 feet of gas passing per hour, the gas was cooled in the following ratio by the several columns :—

TEMPERATURE OF GAS.

Inlet.	Col.1.	Col.2.	Col.3.	Col.4.	Col.5.	Col.6.	Col.7.	Col.8.
103°	79°	67½°	61°	58°	56½°	56°	55½°	55°

It will be seen from these observations that this quantity of gas was effectively cooled by four columns, only 3° of temperature being lost by its passage through the last four columns.

After leaving these condensers, there is still a considerable quantity of tarry matter mechanically suspended in the gas, which renders it distinctly visible when allowed to issue with force from a small aperture; to remove this as much as possible before the gas is introduced into the lime purifiers, where the tar would interfere with the proper action of the lime, it is passed in some Works, as at the Western Gas Works, Kensall Green, through a vessel filled with dry coke, called a scrubber. This vessel is shown at s in the drawing, and the gas is forced to ascend through the column of coke, which acts mechanically as a filter, retaining the greater portion of the colouring matter which rendered the gas visible. The scrubber is cleaned by passing steam into it at intervals, which removes the tar. In other places water, in the form of a shower, is employed for washing the gas before it enters the purifiers. The horizontal pipe B allows the gas at certain periods to pass both condensers and scrubber. The gas now escapes through the pipe o to the purifiers.

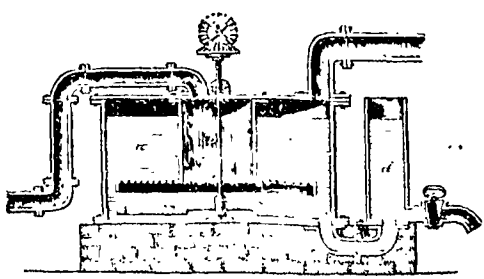
On leaving the condenser, the gas still contains all the ingredients mentioned in the table at p. 567. Several of these are useless for illumination, as carbonic oxide and free hydrogen, which burn with a very faint light, and only tend to dilute the gas; others, on the contrary, are detrimental when burnt, as ammonia, combined with carbonic, muriatic, sulphuric, and sulphurous acids and sulphuretted hydrogen. Sulphuretted hydrogen blackens metals and oil colours when it is evolved with the gas and not

ignited; when burnt, it forms sulphurous acid and water, which becomes gradually converted into sulphuric acid by the oxygen of the air; ammonia escapes unconsumed, or in combination with the sulphurous acid produced by the combustion of sulphuret of carbon; sulphuret of carbon and sulphocyanogen, when burnt, produce sulphurous acid, the cyanogen affording carbonic acid and nitrogen. The purification of the gas has reference only to the separation of the latter class of impurities, the chemical nature of carbonic oxide and hydrogen not admitting of their being removed in an economical manner.

The substances to be removed consist, therefore, of carbonic acid and sulphuretted hydrogen, with small quantities of ammonia in combination, and compound of cyanogen. The quantities in which some of these exist in Newcastle coal-gas have been estimated at 1½ parts of ammonia, 8 of sulphuretted hydrogen, and 25 parts of carbonic acid in every 1000 measures of gas; but they will necessarily vary with the nature of the coal. The substance first proposed by Henry and Clegg for removing these impurities from the gaseous mixture was hydrate of lime, and its efficacy was fully tested on a large scale at a very early period by Winsor. Even to this day, notwithstanding the numerous propositions for substituting other means of purification, lime has been found in every respect the most economical and generally applicable agent for the purpose, particularly as it does not injure the illuminating power of the gas.

Wet-lime Purifier.—In the first instance, lime was employed stirred up with water, or as milk of lime, in the apparatus shown in Fig. 365. To the lid of the outer vessel, a funnel-shaped pipe, expanding considerably below, is attached, and dips some distance into the milk of lime *a*. The gas entering through this pipe, forces its way through the milk of lime, and escapes by the apertures in the lower part of the funnel. An agitator *b*, worked by rack and pinion through the stuffing-box above, is employed to keep

FIG. 365.



the milk of lime in constant motion, preventing the lime from settling to the bottom, and prolonging the time of passage of the gas through the liquid. The vessel is discharged and filled by means of the additional pipe *d* and the stopcock, while a syphon-pipe below prevents any escape of gas.

Wet-lime purifiers, of very similar construction, are still in use at most gas-works, although the pressure exerted upon the gas in the retorts by the column of liquid through which it has to pass in the purifiers is very objectionable, increasing the deposit of carbon and the escape of gas through every accidental crevice. The head of water in old purifiers often amounted to 28 inches; but this may be reduced to 8 or 9 without inconvenience. Darcet proposed to assist the passage of the gas through the milk of lime, and at the same time lessen the pressure, by employing an Archimedean screw, revolving in an opposite direction to the flow of gas.

Dry-lime Purifier.—The simplest and most effective plan, by which all increase of pressure is avoided, and which has been very generally adopted, is that first introduced by Berard. This apparatus is known as the *dry lime purifier*, and consists of a square or round iron vessel, containing a number of iron gratings or shelves, upon which moist slaked lime is spread in layers of 2 or 3 inches in thickness.

Moss is sometimes mixed up with the slaked lime to render it more porous, and expose a larger surface to the gas. Each purifier is furnished with a movable lid in the form of an inverted box, the sides of which are 10 inches deep, and dip into a groove filled with water, which effectually prevents the escape of gas.

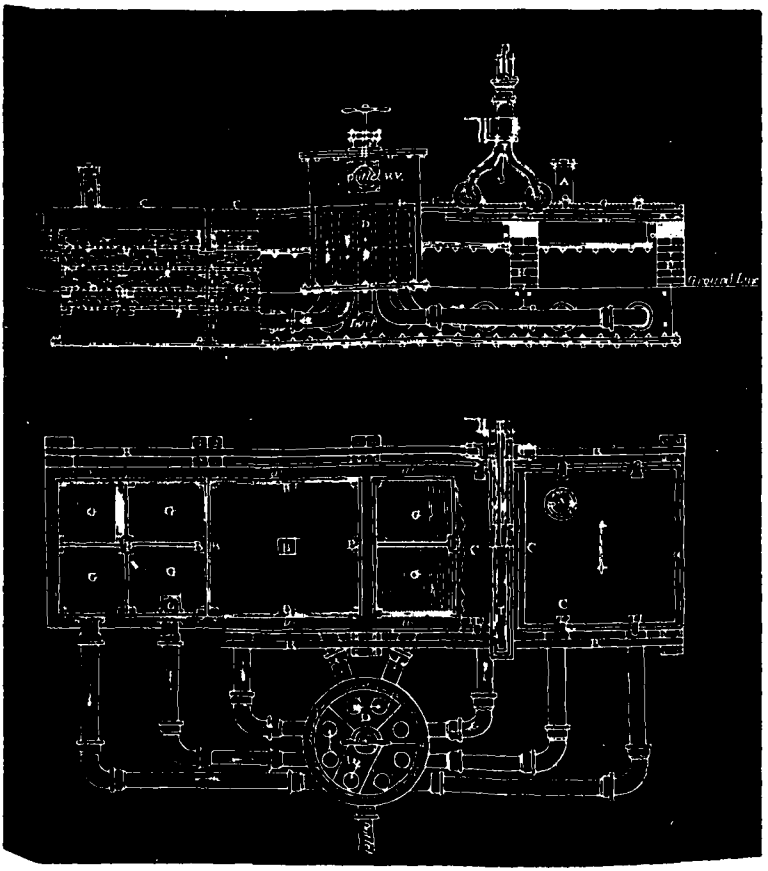
Three or four of these purifiers are generally used in connection with each other, the gas being passed through three successively, while from the fourth the impure lime is being removed, and a fresh supply introduced.

Clegg states that 2 bushels of hydrate of lime, which is equal to 1 bushel of dry lime, will form a layer of 2½ inches upon a surface of 25 square feet, and this quantity of lime will sometimes purify as much as 10,000 cubic feet of gas, although double the quantity is often required. In France, 2½ bushels of lime are used for every ton of coal carbonised, or for about 7,000 cubic feet of gas, the lime being changed every 24 hours.

A set of dry-lime purifiers, of the most modern construction, is shown in Fig. 366. Four trays for supporting the lime, one above

the other, are placed in each, and each is provided with an inlet and outlet pipe, communicating with a common cylindrical vessel D, constructed with an hydraulic valve and movable cap, which enables the gas to be conducted successively through any three of the

FIG. 366.



purifiers, leaving the fourth at liberty to be cleaned. In the drawing, the direction in which the gas passes through the three purifiers is shown by the arrows, the purifier C not being in use.

The cost of purification by lime is very differently estimated by engineers. Mr. Croll reckons it at ¼d. per 1000 cubic feet, while Mr. Barlow estimates the cost at ⅜d. per 1000 in dry-lime purifiers. The same weight of lime used in the wet purifier is certainly

capable of purifying a greater quantity of gas; and some even assert that a bushel, used in the state of milk of lime, will purify 25,000 cubic feet, and from 18,000 to 20,000 cubic feet is actually purified in large works by that quantity.

The action of the lime, according to Graham, is very much increased by the addition of sulphate of soda, which has also the effect of removing both the ammonia and sulphuretted hydrogen, and thus forming a most complete purifier. We do not know why this suggestion has not been adopted. The extra cost of the Glauber's salt, and some practical difficulty in obtaining the soda as hyposulphite, into which it is ultimately converted by the action of the air, may, perhaps, be the cause. The lime, when properly used in sufficient quantities, completely removes the carbonic acid and sulphuretted hydrogen, becoming converted into carbonate, and into sulphide of calcium, while about one-fifth always remains in the caustic condition. Ammonia is also mechanically arrested to some extent by the lime in the purifier, and it is stated that coal-gas, previously deprived of its ammonia by other chemical agents, is not so perfectly freed from its other impurities by lime as when ammonia is present. How the ammonia exerts this influence upon the absorbing power of the lime still remains to be explained.

The mechanical retention of the ammonia is one of the chief causes of the intolerable stench which gas-lime evolves when exposed to the air. Sulphuret of calcium evolves sulphuretted hydrogen slowly when decomposed by the carbonic acid of the atmosphere, but if ammonia be not present, part is converted into hyposulphite of lime, which has no smell. In the latter case, however, carbonic acid is rapidly absorbed by the ammonia, and a neutral decomposition then ensues between the sulphuret of calcium and carbonate of ammonia, producing carbonate of lime and sulphide of ammonium, which escapes with its characteristic odour. So great is the nuisance produced by the effluvia from gas-lime, that numerous plans have been at different times suggested for its prevention. At first it was thrown under the ash-pit of the furnaces, when the vapours escaped into the fire, and were destroyed; but this plan is quite impracticable in large works. It was then proposed to drive off the sulphur by distillation in a close retort, but this was not found remunerative. The best plan appears to be that proposed by Mr. Palmer, and carried out by Mr. Evans, of sending air through the refuse lime without removing

it from the purifier, the latter being connected by a pipe with a chimney draught. The sulphuret thus becomes oxidised, and is then inodorous, the ammonia is driven off, while the hydrate and carbonate of lime remain unaltered, and can be again used for purifying fresh portions of gas. The economy of this process is such that 15,000 cubic feet of Newcastle coal-gas can be purified by one bushel of lime, which is left in a perfectly inodorous condition. A considerable portion of hyposulphite of lime must thus be produced in the refuse, which, as remarked by the author of "Chemistry of Gas-lighting," would be admirably suited to remove the ammonia from gas before it entered the ordinary lime-purifier, and would then afford a very cheap and valuable manure, containing carbonate of lime and hyposulphite of ammonia; or the latter salt might be converted by carbonate of soda into hyposulphite of soda, and sold as an antichlor for the use of paper-makers.

A considerable quantity of ammonia being often left in the gas after it leaves the lime-purifiers, various methods have been introduced for removing this, either before or after it passes the lime-purifiers, and converting it at the same time into a source of profit. When these several schemes were first patented, the sole object appeared to be the utilisation of the ammonia, and too little attention was paid to the effect produced by the various reagents employed upon the illuminating power of the gas. It has already been stated that the removal of the whole of the ammonia diminishes the power of the lime in the purifiers: it has also this inconvenience, that naphthaline, a solid crystalline hydrocarbon which accompanies coal-gas, is far more liable to be deposited in the pipes in a solid form, causing an obstruction, than when ammonia is present; and although it may be desirable to remove an excess of naphthaline, still its presence in the state of vapour must increase the illuminating power of the gas. If the ammonia were present in coal-gas in sufficient quantity to saturate both the carbonic acid and sulphuretted hydrogen, the purification would be more easily effected than is actually the case. A neutral metallic salt, forming a fixed sulphuret and carbonate, would remove the whole of the sulphur and also the carbonic acid in combination with its base, while all the ammonia would be arrested and combine with the acid of the salt. The quantity of ammonia existing in the gas, however, is quite insufficient to saturate either the sulphuretted hydrogen or the carbonic acid, and hence the necessity for employing some alkaline or basic substance for their removal.

Metallic salts may be employed for the removal of the sulphuretted hydrogen with the ammonia, but these have always more or less a prejudicial action on the illuminating power of the gas, by absorbing some of the heavy hydrocarbon vapours, and the amount of carbonic acid remains undiminished. Earthy salts, as sulphate or muriate of lime, have no injurious action upon the illuminating power, and will remove ammonia and a portion of the carbonic acid, but far the greater portion of the latter will still remain in the gas with the whole of the sulphuretted hydrogen. None of these substances, therefore, supersede the use of lime. Acids have been and still are employed for the removal of the ammonia; but, besides injuring the illuminating power, they are not so economical as metallic or earthy salts, and they do not arrest the sulphuretted hydrogen or carbonic acid.

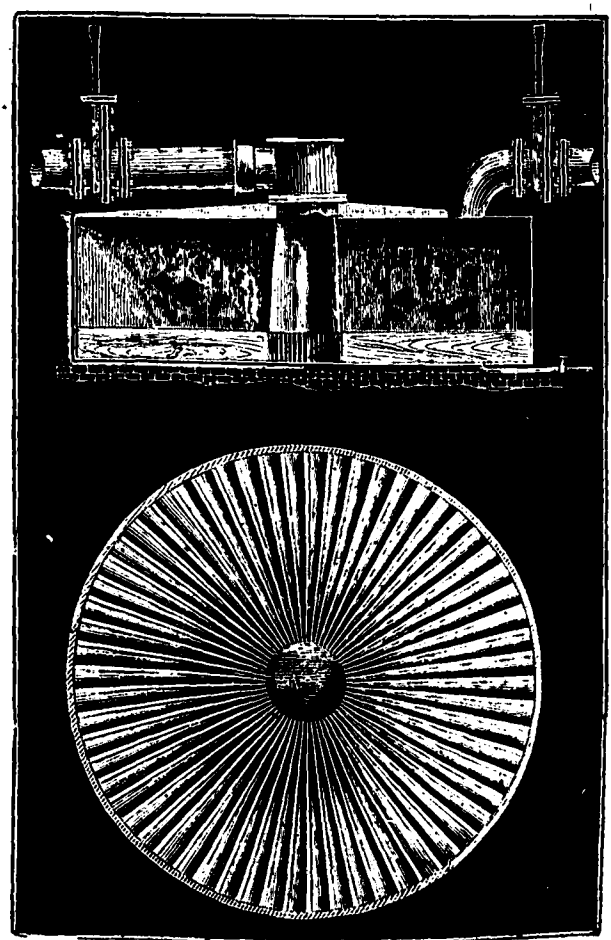
The best mode, theoretically, of purifying the gas, would certainly be to pass it first through an earthy salt, such as sulphate or muriate of lime, which would remove ammonia and a portion of carbonic acid; then through oxide of iron, or some metallic oxide, which would absorb the sulphuretted hydrogen; and lastly through lime, for the separation of the carbonic acid. By an arrangement of this kind all nuisance would be avoided, the products in each case being inodorous.

Pénot first suggested the sulphate of lead waste from the cotton print works as a means of removing ammonia; he suspended it in water in the manner of milk of lime. Sulphate of ammonia was produced on the one hand, and sulphuret of lead on the other; but a lime-purifier was still required to remove the carbonic acid, and the sulphate of lead could not be obtained in sufficient quantity, nor is it sufficiently cheap for use in the gas-works. Chloride of lead has also been recommended by Mr. Loth, and is still employed, in the moist state in some cases, on the shelves of a dry lime-purifier. Another substance for purification was first proposed by Mallet, which is the protosulphate of manganese, produced in abundance in the bleaching powder works; green vitriol, or sulphate of iron, has also been employed. In using any of these salts, as well for the preservation of the vessels as for obtaining the proper action, it is recommended to neutralise the excess of acid contained in them by the ammoniacal water of the tar cistern. The gas is often brought into contact with the solutions in the form of a shower, producing a pressure of not more than 4 to 6 inches of water, but they do not remove the whole of the carbonic acid or sulphuretted hy-

drogen, if in combination as a higher sulphuret of ammonium, and hence a lime-purifier beyond Mallet's apparatus is found necessary.

Lowe proposed the use of water, a weak acid solution, or the ammoniacal liquor itself, allowed to fall upon a coke column

FIG. 367.



through which the gas was passing in an upward direction, as a ready means of removing ammonia.

Croll arrests the ammonia, and converts it into a commercial commodity in a manner which is said not to injure the quality of

the gas, by using a solution of weak acid, a fresh portion being gradually added as the first becomes saturated.

The gas is conducted into a circular vessel, Fig. 367, lined with lead, which is separated at the bottom into a number of compartments, represented in Fig. 367, 8 or 10 inches in height, which support a leaden plate extending to within about 5 inches of the periphery of the vessel. The vessel is filled with a solution containing about 2½ lbs. of acid to 100 gallons of water up to the level of this plate, below which the gas is introduced and distributed through the various compartments.

The gas being thus brought into intimate contact with the acid, it is quickly saturated, when a fresh supply is furnished from a reservoir placed at a higher level. Two or three of these vessels are required in large gas-works to be used consecutively, and when 10 feet in diameter and 3 feet deep, they will purify 500,000 cubic feet of gas every twenty-four hours, and require re-charging with acid about every second day. The liquor thus obtained yields 80 ounces of sulphate of ammonia for every gallon that is evaporated, instead of 14 ounces, which is the average quantity obtained from the ordinary ammoniacal liquor of the condensers.

Chlorides and sulphates of manganese, iron, or zinc, may be used instead of sulphuric acid, and the compounds formed from these salts may be again decomposed, and the products re-applied in the purifying process. The waste steam from the engine employed for pumping the gas from the retorts may be employed for evaporating the sulphate or muriate of ammonia.

Three metal cylinders, Plate III. A B C, on different levels, are often used. The metallic solution is brought by the pump *f* to the pipe *g*, which conveys it into the cylinder C. A water lute pipe *h* permits the excess to flow through the tube *g'* into the second cylinder B, and by a similar contrivance into the third A, and thence into the tank K. The gas follows the contrary direction, arriving by the pipe *a a'* in the cylinder A, where it is washed by the metallic solution, and thence through the other cylinders to the ordinary dry lime-purifiers.

The agitators *i i' i''* are kept moving slowly by means of belts, or occasionally by handles, in order to prevent the insoluble sulphurets and carbonates from accumulating at the bottom, as well as to present a new surface to act upon the gas. When this precipitate increases in quantity, it may be removed by the cock *j j' j''*.

The whole contents are collected in the tank K, and the clear

liquor is run off into another cistern M, whence the ammoniacal liquor is pumped by means of *f* into suitable evaporators.

Absorbents employed in a moist but not wet condition in the dry lime-purifiers, have lately received the preference for removing the sulphuretted hydrogen. The salts of iron, manganese, zinc, and nickel, employed in this manner, absorb ammonia and such portion of the sulphuretted hydrogen as is in combination with it; but they allow the free sulphuretted hydrogen to escape. The salts of lead, bismuth, tin, and antimony, absorb the whole of the sulphuretted hydrogen, but their cost has generally prevented their application. The oxides, either hydrated or anhydrous, of manganese, iron, zinc, lead, copper, and antimony, have all been made the subject of patents, and the oxides of iron, lead, and antimony, have been practically employed with excellent results in this country. Mr. Croll, by a patent dated 1840, appears to have been the first to secure the right of employing the oxides of manganese, zinc, and iron, in a moist condition, placed in a dry lime-purifier, for separating sulphuretted hydrogen from gas after the ammonia had been removed by chloride of manganese, or some similar metallic salt.

Acids do not remove the ammonia so effectually as metallic salts; this is proved by the re-appearance of ammonia in gas which has passed an acid purifier, and been rendered neutral to test-paper when passed through a lime-purifier. The large quantity of carbonic acid in the gaseous mixture is supposed to exert its action in such a manner as to allow bicarbonate of ammonia to escape the action of the stronger acid. The bicarbonate is neutral to test-paper, but becomes decomposed by the hydrate of lime.

Mr. Laming since patented the use of oxide of iron, mixed with chloride of calcium or sulphate of lime, in the same vessel, for the removal of the ammonia and sulphuretted hydrogen in a single operation,—this latter clause forming the only essential difference between the two processes. Croll likewise proposed roasting the waste oxide of manganese, to which material he appears at first to have given the preference, in an oven under constant agitation, by which means the sulphur was converted into sulphurous acid, and the oxide obtained in a condition to be again used in the purifier. This process of revivifying the oxides by artificial heat, which had been previously tried with the waste gas-lime, does not pay; and as lime removes sulphuretted hydrogen, and is much cheaper than any of the substitutes proposed, the only benefit derived from them

consisted in the abatement of the nuisance produced by the evolution of the sulphuretted hydrogen from the waste lime. Mr. Laming subsequently observed that the simple exposure to the air of the hydrated oxide of iron, when removed from the purifiers, had the effect of removing the sulphur, and rendering the oxide again fit for use.

For this process Mr. Laming obtained a patent in France, but the plan having been practised by Mr. Evans in this country, no patent could be obtained for it, and it is therefore public property. Mr. Hills also lays claim to the hydrated and precipitated oxides of iron, and various other earthy and alkaline salts, when mixed with sawdust or breeze in the dry lime-purifier. Messrs. Lowe and Evans have patented the use of anhydrous oxide of iron, which appears to be the most successful of all the agents for removing sulphuretted hydrogen. The chemical reaction which occurs in the purifier when the hydrated or anhydrous oxide of iron is employed, consists in the formation of water, the conversion of a part of the oxide into protosulphuret of iron, and the deposition of sulphur. Exposed subsequently to the air, the protosulphuret absorbs oxygen, and is partly converted into sulphate of the protoxide, particularly when ammonia is also present in the mixture. The heat evolved by this process of spontaneous oxidation is often sufficient to ignite the sulphur; the whole mass becomes red hot, and volumes of sulphurous acid are evolved, while the great heat generated seriously injures the absorbent properties of the oxide. When not ignited, however, the mixture after exposure is said to be capable of purifying a larger volume of gas than when used for the first time,—a circumstance which it is difficult to explain, unless it be due to the formation of a portion of sulphate.

When a mixture of chloride of calcium and any of the oxides of iron is employed in the purifier, the gas containing sulphide of ammonium, sulphuretted hydrogen, and carbonic acid, might be supposed to give rise to the formation of chloride of ammonium, sulphide of iron, and carbonate of lime. The oxidising action of the air upon this mixture would tend to produce sulphate of iron from the sulphide, which would be again decomposed by the carbonate of lime in the moistened mass, giving rise to free carbonic acid, sulphate of lime, and oxide of iron. When again used in the purifier, the sulphate of lime would perform the same function as the chloride of calcium in the first instance, and so on until the whole of the sulphuric acid in the sulphate of lime was converted

into sulphate of ammonia, when a fresh addition of earthy salt would be required.

Such, however, does not appear to be the mode of action with the oxides of iron, only a small proportion of which are converted into sulphides. The hydrogen of the sulphuretted hydrogen is, however, oxidised at their expense, forming water, while a large quantity of sulphur is deposited in an uncombined condition; the action is, therefore, in part similar to that which occurs, and is familiar to every practical chemist, when sulphuretted hydrogen gas is carried through a solution of a persalt of iron, the peroxide being reduced to the state of protoxide, and sulphur deposited. Some have advanced the explanation that a sesquisulphide of iron is formed, which, on subsequent exposure to the air, is converted again into peroxide of iron, water, and free sulphur; but the quantity of oxide of iron required to purify the gas fully from sulphuretted hydrogen is four times greater than should be theoretically required upon this assumption.

The atmosphere, composed of the vapours of hydrocarbons, may materially affect the order of chemical affinities in the dry lime-purifiers; and until this question has been more fully made the subject of experiment, it would be premature to offer any decided opinion upon the precise chemical action of the oxides of iron upon the ingredients of the gas.

The plan of ventilating gas-lime carried out by Mr. Evans, renders the lime itself perfectly inodorous; but the vapours which pass away from it in the process of ventilation, unless carried through the furnace and thus destroyed, are evolved from the chimney, and may then give rise to nuisance in the neighbourhood. Such was the case at the works of the City of London Gas Company; and in order to prevent the nuisance complained of, Mr. Mann, the engineer, carried the current of ventilating air, after passing from the lime-purifiers, through another purifier containing oxide of iron, by which the noxious gases were entirely absorbed; and the current of air being kept up, the oxide of iron, which at first becomes saturated with sulphuretted hydrogen, is again oxidised, and may be used repeatedly for the same purpose, while water and nitrogen are evolved, and sulphur deposited.

The author of the "Chemistry of Gas-lighting" suggests a mixture of clay or loam with the oxide of iron in place of the saw-dust, which is now generally employed to render the mass porous: the alumina being then intimately mixed with the oxide would tend

to prevent the excessive heat produced by oxidation, and in case of ignition the oxygen would not be rendered inert with reference to the absorption of sulphuretted hydrogen, as it is well known that a mixture of oxide of iron with alumina may be heated to redness without impairing its absorbent properties. A mixture of this kind, without organic matter, would also admit of the sulphur and cyanogen compounds being more easily removed from the saturated compound.

Sulphurous acid completely decomposes sulphuretted hydrogen, sulphur being deposited, and pentathionic acid produced whenever the two gases are brought into contact; and this agent has often been looked to as a means of purifying coal-gas, but no practical application of it has been proposed.

Johnson has patented the use of boracic and phosphoric acids, the bisulphates and biphosphates of potash, soda, or ammonia, with other salts of alumina and the earths, as absorbents for ammonia, together with the salts of iron and manganese.

Acid phosphate of lime, containing some sulphuric acid as obtained by the action of oil of vitriol upon bone-earth, has been applied with success by some of the London companies; the product, a phosphate and sulphate of lime and ammonia, being a very valuable manure.

The silicious gravel, containing oxides of iron and manganese, ferruginous clay and loam, and the phosphate and subphosphate of iron of the tertiary formation, have also been employed for removing ammonia and sulphuretted hydrogen.

Clay of the ferruginous kind, in conjunction with dry lime, has lately been patented as a means of purifying gas from all its impurities, and is particularly recommended for removing sulphuret of carbon, which escapes all other purifiers yet tried. Many statements have been published in favour of the action of clay in increasing the illuminating power, and as a means of removing the sulphuret. Mr. Lewis Thompson, however, distinctly states that clay and the various compounds of alumina have no such action; nor, in the course of a very extensive series of experiments with all conceivable salts and mixtures, did he find one which effectually removed that compound at ordinary temperatures. By passing coal-gas, however, through caustic baryta or caustic lime at a red heat, the whole of the sulphuret of carbon was removed without injury to the illuminating power. The small quantity of ammonia always left in the gas by the ordinary process of purification is practically

unimportant, as it combines, on the combustion of the gas, with the sulphurous acid generated from the sulphuret, and the sulphite of ammonia thus formed is speedily converted by the oxygen of the air into sulphate of ammonia, a perfectly innoxious salt. The action of the lime or baryta not only removes the sulphuret of carbon, but likewise the inappreciably small quantities of basic substances which give the peculiar odour to the gas. Leakage would therefore not be perceived at once, as is now the case, if this process were adopted, and serious accidents might be apprehended in consequence.

Mr. Laming has lately taken a patent for removing the carbonic acid from gas by means of ammonia, or a liquor containing salts of ammonia, but capable of absorbing more. He applies the liquor in a scrubber filled with coke, brickbats, coarse gravel, or other similar material, over which the ammoniacal solution is allowed to trickle in a thin stream, meeting the current of gas as it ascends. The sulphuretted hydrogen is subsequently removed by one of the oxides of iron in a dry lime-purifier. A foreign patent has also been secured by Newton in this country, for employing ammonia in a scrubber to remove both carbonic acid and sulphuretted hydrogen, and subsequently washing the gas with water to remove the ammoniacal salts. Sulphurous acid is also claimed in this patent for assisting the ammonia in removing the sulphuretted hydrogen.

Oil-gas.—It appears, at first sight, both inexpedient and superfluous to distil oil for the production of gas, when we consider that oil can be burnt in lamps without any further preparation, while it loses carbon by deposition in the retorts. Purified lamp-oil is consequently never used; but gas can be prepared from impure oils, train-oil, or refuse fat, with as much ease as from the purer kinds. The manufacture of oil-gas is, therefore, under certain circumstances, an admirable means of using up such materials for the production of light, as could not otherwise be employed, or only applied to the lowest uses.

In 1815 Mr. J. Taylor obtained a patent in this country for the manufacture of gas from refuse fatty matters, and his plans were carried out at the gas-works in Liverpool, Bristol, and Hull; but the cost of raw material not being able to compete with that of coal, the oil-gas manufacture has been discontinued in this country.

The experiments of Henry, which extend also to this part of the

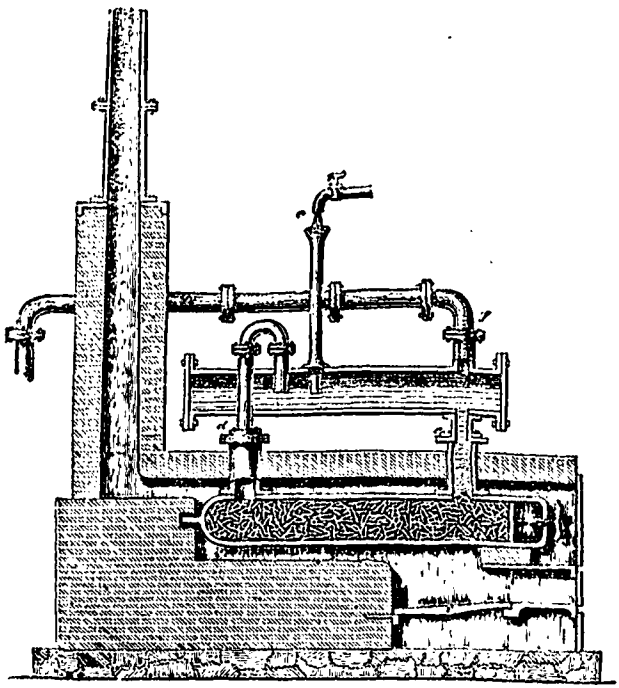
subject, show at once the plan that must be adopted upon a large scale. His results were as follows:—

Substances Distilled.	Temperature of the Distillation.	Specific Gravity of the Gas.	Absorbed by Chlorine.	Light Carburetted Hydrogen.	Carbonic Oxide.	Hydrogen.	Nitrogen.
			In 100 parts of Illuminating Gas.				
Oil ...	Bright red heat	0.464	6	28.2	14.1	45.1	6.6
	Ditto	0.590	19	32.4	12.2	32.4	4
	Lowest possible temperature...	0.758	22.5	50.3	15.5	7.7	4
Train-oil.	Low red heat ...	0.906	38	46.5	9.5	3	3

It appears, then, that oil-gas is superior to that obtained from coal, as is also shown by its density, and that the produce, dependent chiefly upon the temperature, is of the best quality when obtained at a low red heat. This temperature suffices to convert the oil into gas, but is not sufficiently high to decarbonize the gas to any great extent. The apparatus for obtaining gas by the distillation of oil is represented in the drawing opposite, Fig. 368. The retort *a* is filled with bricks, or lumps of coke, which very materially increase the red-hot surface, and promote the evolution of gas, shortening the time which the gas already produced has to remain in the red-hot vessel. The second cylinder *b* serves both as reservoir and hydraulic main, *a* and *b* being connected in two places *d* and *e*. Oil flows from a large cistern above the apparatus in a constant stream through the tube *c* into *b*, which is thus kept filled up to a certain level. From *b* the oil descends through *e* to *a*, where it is converted into gas and tar, both of which are volatilized, and return through *d* to *b*. The pipe *d* is bent, and its open end delivers just below the fluid level in *b*, so that the vapours of the decomposed oil must constantly pass through the reservoir of oil, and deposit their tar. The retort *a* is, therefore, constantly supplied, not only with oil, but with a mixture of oil and tar, in such a manner that all the condensed products return to the retort together with a fresh quantity of oil, until they are completely converted into gas. If the operation be conducted in a long tube, inclined at the hinder part, while the front is kept cool, hardly any tar is produced. The gas which collects above the oil in *b*, passes on through the tube *g*. The objections to the use of metallic vessels in distilling coal, are not applicable to the distil-

lation of oils; and cast-iron vessels are, therefore, always employed, and heated over a furnace constructed in the usual manner. According to trustworthy statements, 1 cubic foot or about 4 gallons of oil produce 600 to 700 cubic feet of gas, which is equivalent to from

FIG. 368.



90 to 96 per cent of the weight of the oil: the remainder (excepting some unavoidable loss) consists of carbon, which is deposited upon the coke or bricks. According to Dr. Fyfe, a gallon of oil seldom yields 100 cubic feet of gas of good quality, on a manufacturing scale. That made at Leith, and in private gas-works at Edinburgh, had a specific gravity of from 645 to 710, containing 32 per cent of matter condensable by chlorine. In this manufacture about one-half only of the oil is converted into gas. The production of oil-gas is a continuous process, and thus differs from the distillation of coal. The retorts only require opening now and then, for the removal of the deposit of graphite. Vapours of the same composition and properties are found in oil- and coal-gas. Thus, according to Hess, all the volatile empyreumatic oils, which

occur mixed with each other in the tar from oil, have the same composition per cent as olefiant gas. In the oil-gas made in this country, and submitted to a pressure of 20 or 30 atmospheres, in order to render it portable, Faraday observed that 7500 volumes of gas were converted into one volume of liquid; and among the oily bodies of which the liquid is composed, and which contain from 80 to 90 per cent of carbon, he was enabled to study some in an isolated state, as triyle (C_3H_3), ditriyle (C_2H_4), and a third hydrocarbon (C_2H_3).

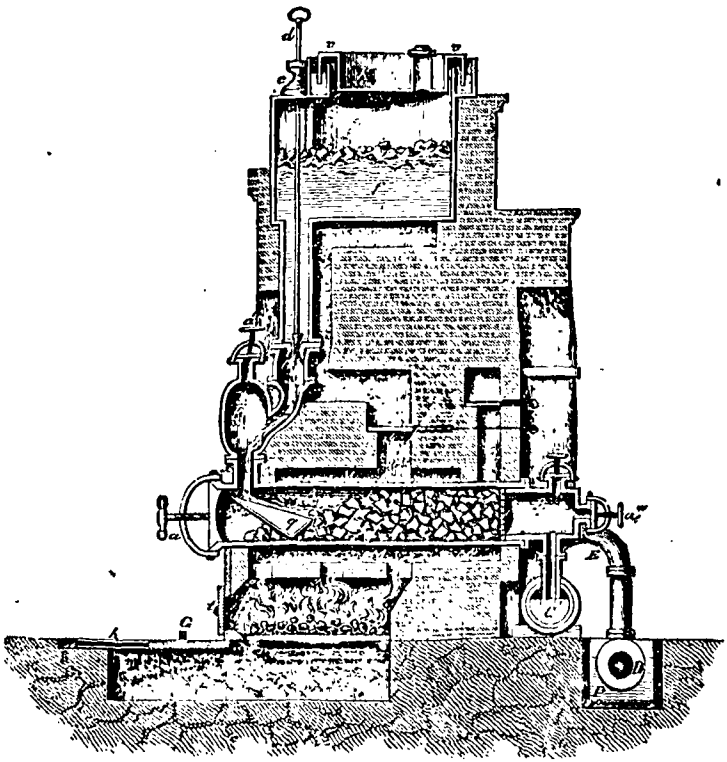
Resin-gas.—Resin could be distilled in the oil-gas apparatus, if it were liquid at ordinary temperatures, but such not being the case, it requires to be liquefied by heat, or some solvent, before it is allowed to flow into the retort. Coal-tar naphtha is often used to dissolve the resin, or the oil which results from its own distillation. When the latter is employed, the flame from the furnace, before escaping into the chimney, is allowed to play upon the reservoir of resin. As the resin melts, it trickles through a sieve into a second division of the vessel, leaving the impurities and the solid portion behind, where it is mixed with an equal part of the resin-oil. Thus a solution which will no longer solidify is obtained, and with it the retort is supplied, as with oil in the former case. When the gas, either from resin or oil, has parted with its condensable vapours in the coolers, it is in a fit state for consumption, no further purification being required.

About the year 1819, Professor Daniell constructed a very ingenious apparatus for distilling resin, for the Resin Gas Company at Bow; but the process was ultimately abandoned, in consequence of the comparative cheapness of coal, although from 1000 to 1200 cubic feet of gas, of 850 average specific gravity, were obtained from one cwt. of resin, and 2 cubic feet of resin-gas afforded as much light as 5 cubic feet of ordinary coal-gas.

One of the best arrangements of apparatus for making resin-gas, and which has stood the test of practice, is that which has been extensively carried out by Chaussenot, and is shown in Fig. 369: the resin is here melted without any additional solvent, and the oil or tar collected and disposed of as a secondary product. The draught to the fire-place *P* is regulated through the ash-pit by means of the plate *G*, which can be moved horizontally backwards and forwards in the groove *h*. The air passing from below through the grate and fuel *r r*, creates a powerful flame, which passing, in the first instance, through the apertures *g g g* in the roof, plays round

the retort *A*, in the space *M*, and then, before reaching the chimney, heats the vessel *I* containing the resin, by means of the flue *N N*. If this vessel requires filling, the fire is shut off from *N* by the damper *b*, and is allowed free egress at the aperture *O*, by

FIG. 369.



drawing back the damper *c*. Both the dampers are worked by iron rings and rods from without. In Chaussenot's apparatus, it is not necessary to dissolve the resin in tar-oil, because the vessel *I*, in which the resin is melted, and the conducting tube *H*, being constantly surrounded with hot air, no solidification of the melting resin at the bottom *f* can take place. Combustible gases are generated by merely melting the resin, which may possibly endanger the whole apparatus. To avoid such contingencies, the edge of the resin cistern *I* is furnished with a groove filled with water *u u*, into which the lid *K* dips at *v v*, and is consequently secured by a water-valve. By means of an aperture in the lid, the

vapours can be conducted into the chimney or under the grate. The melted resin flows consecutively through *H*, *G*, and *x*, into the retort *A*. Between *G* and *H* is a plate *o*, with a funnel-shaped aperture in the middle, in which the conical end of the rod *d* is movable. If this is raised through the stuffing-box *e*, a more abundant supply of melted resin is furnished to the retort; if it is pushed down, the stream diminishes, or the flow ceases entirely. The resin flowing from *x* is carried to that part of the retort containing the coke by means of the inclined plate *q*. The coke is prevented falling into the neck of the retort by the grating *l*; the gas escapes through a descending pipe *w* to the tar-cistern *C*, and from thence through *E* to the coolers *D*, which are immersed in water in a long trough *P*. *C* is always nearly filled with tar, that the mouth of *w* may remain immersed; this, therefore, dips into *C*, whilst the gas-pipe *E*, behind the sectional level in the drawing, only just passes through the material of the main *C*. Apertures are constructed in several places, as above *F*, at *a'*, at *a''*, and *a'''*, by which the apparatus may be cleaned at intervals; these are firmly closed, during the process of distillation, by flat plates of iron firmly screwed on by means of iron brackets, similar to that used for closing the mouth of the retort *a*. Distillation goes on continuously in this apparatus, until the deposition of carbon renders a renewal of the coke necessary.

The resin-gas formerly made at Frankfort-on-the-Maine and Antwerp is said to have been little superior to coal-gas in illuminating power, but from 1500 to 2500 cubic feet of gas were obtained from 1 cwt. of resin.

Resin contains 10 atoms of carbon, 7 of hydrogen, and 1 of oxygen. The weight of the compound atom is therefore 75. Supposing the whole of the hydrogen to unite with the quantity of carbon required to form olefiant gas of sp. gr. 976, the utmost that could be produced from an atom of resin would be 49 parts out of 75, or about two-thirds of its weight, accompanied by some carbonic oxide and carbonic acid. If any of the hydrogen escape uncombined, or in the form of light carburetted hydrogen, a proportionate quantity of carbon must escape conversion into gas, and hence the loss which must always attend the distillation of resin, even supposing that none of it were distilled unchanged or converted into resin-oil.

Dr. Fyfe obtained the following quantities of gas by distilling

resin at different temperatures, of which he also ascertained the relative specific gravities and illuminating power.

Temperature of Distillation.	Quantity of gas per lb. of resin.	Sp. Gr. of gas.	Per-centage of carbonic acid.	Durability or quantity consumed per hour in jet 1-33 inch diameter and 5-inch flame.	In Argand burner, consuming 5 feet per hour, illuminating power was equal to candles,	Resin not converted into gas. Fraction of quantity distilled.
	Cub. feet.			Cubic feet.	Per cubic foot.	
Heat employed for coal-gas	10.	640	10	1.2	2.45	$\frac{1}{2}$
Dull red heat.	6.2	657	6	1.25	2.27	$\frac{2}{3}$
Somewhat above dull red heat ...	8.42	419	8	1.43	—	$\frac{1}{4}$
Ditto	9.	613	—	—	—	$\frac{1}{2}$
In White's retort, without water-gas ...	8.8	574	—	1.12	2.	$\frac{3}{5}$

He considers, therefore, "that the quantity of gas that can be produced from resin in practice will not exceed 8 or 9 cubic feet per lb., that is, about 1000 cubic feet per cwt.; that the gas, after being purified, will be of specific gravity not much beyond 600, the condensation by chlorine not beyond 8 or 9 per cent; a cubic foot of gas not giving more than the light of from 2½ to 3 candles."

Hydrocarbon or Water-gas.—It is well known that water passed in the form of steam over red-hot iron, is decomposed; its hydrogen being liberated in the form of gas mixed with a little carburetted hydrogen from the carbon of the iron, while the iron becomes converted into oxide. If coke or charcoal be substituted for iron in this operation, hydrogen, carbonic oxide, and carbonic acid gases are produced in variable quantities, according to the temperature employed; carburetted hydrogen being only present in very small quantity, according to Dr. Fyfe. This mixture of gases is very slightly luminous, and consequently of little value itself as a source of light. It has, however, been proposed by numerous patentees, either as a means of diluting very rich illuminating gases such as those obtained from oil, resin, tar-oil, and cannel coal, or sometimes alone, at others in connection with the vapours of water, as a means of decomposing the tar vapours evolved from coal, fat, or resin, during distillation. Thus employed, the gases from

water are said not only to mingle, and by their presence in the form of a current to drive the gases rapidly from the retorts, but to be instrumental in converting the vapours of tar into permanent gas, and preventing the large deposition of carbon in the retorts and pipes, which forms so serious an obstacle to the distillation of highly carbonized matters on a manufacturing scale. Both Drs. Fyfe and Frankland, who have investigated the action of the gases evolved from water in connection with the distillation of resin and coal, are agreed that no chemical union with the elements of the tar is brought about when the water-gas is introduced into a retort in which resin or coal is undergoing distillation, although they certainly prevent the large deposition of carbon.

Donovan appears to have been the first who employed the gases evolved from steam, in its passage over red-hot coke or charcoal, for illuminating purposes; and in order to confer upon these the necessary amount of luminosity, he caused them to combine, as he believed, with carbon in the state of vapour, or as produced from the distillation of oil of turpentine and the resinous parts of coal-tar or naphtha. This patent, which was secured in 1830, appears to claim something more than the mere impregnation of water-gas with the vapours of hydrocarbon or naphtha, although it is probable nothing further was really obtained by the processes recommended. In 1832 Lowe introduced his system of naphthalizing coal-gas in the manner described below, by which poor gas is rendered more luminous by being saturated with naphtha vapour. M. Jobard, of Brussels, took a patent in 1834 for passing the gases derived from the decomposition of water over resinous bodies while undergoing distillation; and with him appears to have originated the idea for which Selligue obtained a patent in France in the same year. Selligue's process was used in connection with shale-oil, and was most favourably reported on to the French Academy by Thénard, Darcet, and Dumas. It was introduced at the Royal Printworks, and extolled at the time by Payen.

The bituminous shale of Autun, as used by Selligue, affords, when distilled, from 10 to 20 per cent of oily products, $\frac{2}{3}$ of which consist of a light oil, of specific gravity 0.766 to 0.810, which was used for the production of gas. Three cylinders were employed in the process, set in an upright position in a furnace, where they could be heated to redness. Two of these were filled with wood-charcoal, which could be replaced from time to time; the third was filled with chain and pieces of iron. A thin stream of water flowed into

the first cylinder, and was converted there, in contact with the red-hot charcoal, into carbonic oxide and hydrogen, which process was completed in the second retort, from whence both gases entered the third retort, in which a stream of the shale-oil was being decomposed by the red-hot iron. The carbonic oxide and hydrogen gases from the water here mingling with vapours from the destructive distillation of the shale-oil, constituted the new illuminating gas. By the simultaneous decomposition of 157 lbs. of oil and 160 lbs. of water in this manner, 13461 cubic feet of gas (of 0.65 specific gravity) are said to have been obtained,—and, moreover, of such a quality that its illuminating power was twice as great as that of ordinary gas: 86 cubic feet of this better kind of gas were, therefore, obtained from 1 lb. of oil, whilst the same quantity of shale-oil, treated in the usual manner, would only produce from 15 to 28 cubic feet. So extraordinary a result is quite incomprehensible, nor is it at all explained by the statements proceeding from the high authorities before quoted. The remarkable fact is mentioned, that in the third retort there is no deposition of carbon whatever upon the iron chain, and that, consequently, the gas prepared by Selligue's method must contain all the carbon that is deposited as graphite in the retorts by the ordinary process; they remark further, that Selligue's gas deposits no condensable vapours at $-25°$ C., nor is it deteriorated in quality by that temperature; whence it appears that the value of the gas depends upon its chemical, and not upon its physical constitution; but no facts are given calculated to explain the chemical process concerned in its production. It remains quite inconceivable how the illuminating power of the gas can be doubled by the products of the decomposition of water, consisting as they are known to do of equal volumes of carbonic oxide and hydrogen; and even supposing the latter to be combined with carbon, yet the gas must be diluted with an equal volume of carbonic oxide. Peligot found in 99 volumes of the new gas, 28 carbonic oxide, 15 hydrogen, and 56 carburetted hydrogen (of all kinds). When from 1 lb. of oil 86 cubic feet of gas of 0.65 specific gravity are obtained, these must weigh 4.2 lbs.; 3.2 lbs. of carbonic oxide and hydrogen must, therefore, have been added to the constituents of the shale-oil by the decomposition of water, and yet these only make up 43 per cent of the gaseous mixture, according to Peligot's analysis. Supposing even that a portion of the hydrogen serves to prevent the deposition of carbon, by becoming converted into carburetted hydrogen, yet so large a

proportion of carbonic oxide, which is itself not luminous, can in no way be reconciled with the high illuminating power of the gas.

Mr. Sanders, of the Hibernian Gas-works, made extensive experiments, with a view to render water-gas luminous, as early as the year 1834, and enrolled a patent for his invention in 1835. His plan was to transmit steam through coke, peat- or wood-charcoal, heated to redness in a succession of one, two, or three retorts, so as fully to reconvert the carbonic acid at first produced into carbonic oxide gas: a single retort, with a horizontal partition to within a few inches at one end, was sometimes used for the same purpose. The mixture of hydrogen and carbonic oxide was then passed through cream of lime to remove every trace of carbonic acid, and then into another retort or vessel, also heated to redness, into which were introduced tar, turpentine, resin, oil of resin, petroleum, asphaltum, bitumen (natural or artificial), naphtha, vegetable oils, animal oils, tallow, or caoutchouc, or the volatile oils produced by the destructive distillation of any of these substances. These substances were allowed to enter the retort in regulated quantities, according to the supply of water-gas, by which the more volatile portions were taken up and carried forward. As much naphthaline was thus volatilized, it was found necessary to pass the compound gas through condensers, in which it separated before the gas was allowed to enter the mains. The first idea in this process was to convert the substances containing excess of carbon, by means of steam, into olefiant gas, carbonic oxide, and hydrogen: this, however, failed in practice, the high temperature destroying the olefiant and heavy hydrocarbons, and the patentee was contented with impregnating the purified water-gas with very volatile hydrocarbons, although even this was eventually abandoned as an unremunerative source of illuminating gas.

Many other plans have since been patented to obtain these products. Manby invented a process, in which steam was passed through a retort set in a vertical position in a furnace, and heated to redness. The retort contained anthracite, stone-coal, coke-charcoal, or bituminous coal, together with a mixture consisting of one part of slaked lime, nine parts of silicious sand, and one part of clay. The admission of the steam could be regulated, and a small jet of gas was used in order to judge of the condition of the gas which was being generated.

Val Marino's patent has reference more particularly to the decomposition of tar by the agency of water-gas, although he does

not confine his claim to that substance. Three retorts were employed, one for generating the water-gas, a second for fully decomposing any steam that might escape from the first, and a third in which the tar was decomposed by being heated in contact with an extensive surface of red-hot coke, and into which the gases from the second retort were conducted. Although an attempt was here made fully to decompose the steam before it entered the retort in which the tar was undergoing decomposition, it could not have been entirely successful, and later experimenters have found that steam in contact with iron or charcoal is never entirely converted into hydrogen and carbonic oxide; the oxide exerting a preservative action upon some portion of the aqueous vapour.

Radley likewise obtained a patent in 1845, in which, however, no new principle was introduced. White patented a process in 1847, in which all the prominent points of Sanders' and Val Marino's methods are retained; some slight modifications being made in the mode of decomposing the resin, fat, or tar, by a quantity of iron chain, arranged in the retort in a particular manner, which does not appear to be any improvement upon the coke employed by Val Marino for the same purpose. In 1849, another patent was taken by Mr. White for a different arrangement of the apparatus, particular stress being laid upon a horizontal partition, passing nearly to the back of the retorts, by which the water-gases were obliged to pass over a larger surface of the substances employed for generating the carbo-hydrogens,—a plan already adopted by Sanders.

Two distinct decompositions of the water take place in all these processes, according to the temperature and other circumstances, the precise nature of which has not been traced. In the one, water is decomposed into equal volumes of hydrogen and carbonic oxide gases; in the other, into two volumes of hydrogen and one volume of carbonic acid. It is highly desirable to prevent the latter kind of decomposition as much as possible, so that very little carbonic acid shall be mixed with the gas, but in practice this has not been found possible when resin is used, as much as 16 per cent of carbonic acid being often present in the mixture, which materially reduces its illuminating power. Dr. Fyfe considers the water-gas as a simple diluent of the resin-gas, and as such worthless, or rather a source of additional expense without compensating advantages, more gas being obtained, but of inferior illuminating value. Dr. Frankland, in experimenting upon White's hydrocarbon-gas from resin, found it to contain from 4.72 to 10.78 only of car-

bonic acid, derived chiefly from the water-gas, and this could only be separated completely by using caustic soda in connection with lime in the purifiers.

Dr. Frankland considers that the water-gas performs a most important part in preserving the heavy hydrocarbons from being decomposed, and in becoming itself saturated with the naphthas, which would otherwise be condensed, and which materially increase the illuminating power. The cost of the manufacture cannot be fairly arrived at from the experiments, as a fictitious value has been set upon the secondary product, or the resin-oil. The gas had, after complete separation of carbonic acid, the following average composition, its specific gravity being 0.5913:—

Olefiant gas	8.13
Light carburetted hydrogen . .	29.71
Hydrogen	43.38
Carbonic oxide	18.78
	100.00

and the average quantity obtained from 1 cwt. of resin and 76 lbs. of water was 1503 cubic feet.

Irrespective of the economic value of the process, the results of Dr. Frankland are not in accordance with the opinion of Dr. Fyfe, that the water-gas could only act as a diluent of the resin-gases. From Dr. Frankland's experiments, 1500 cubic feet of gas, instead of 1000, are obtained from 1 cwt. of resin, and these are of the average specific gravity and illuminating power of resin-gas itself, according to Dr. Fyfe.

In many of the works which were fitted up for making hydrocarbon-gas from resin, cannel-coal has now been substituted.

Figs. 1 and 2, Plate III., show the kind of retort, and mode of setting, adopted in several places for generating hydrocarbon-gas from cannel-coal by White's process. Fig. 1 shows an elevation of two retorts in one oven, and Fig. 2 a longitudinal section through one of the retorts. The retorts are 6½ feet long, 25 inches high by 16 inches wide, and have an internal cubical area of 16 feet. The bed of two is capable of producing 10,000 cubic feet per day. Each retort has a horizontal shelf to within 12 inches of the back; a single door in front closes both partitions. The retort A, Fig. 1, is charged with coke or charcoal, which being brought to a strong red heat, water in a thin stream is introduced through the pipe and syphon K. The water being at once converted into steam,

this passes to the back of the upper partition, permeating the coke; and before it again arrives at the front of the lower chamber, is in great part converted into a mixture of hydrogen, carbonic oxide, and carbonic acid gases, which are then carried into the second retort B, charged with cannel-coal. Steam, however, is still present in the mixture, and Dr. Frankland, in his report on the hydrocarbon-gas from cannel-coal, inclines to the opinion that it performs important service in the coal retort in decomposing, in some still obscure manner, the hydrocarbons which would otherwise be condensed; carbonic oxide, a very large quantity of hydrogen, and a less highly carbonated carbo-hydrogen, being produced. The carbonic acid contained in the water-gas, which was not diminished in quantity by passing through resin in the act of decomposition, and was very difficultly separated in the purifiers, is found to be almost completely removed, and probably converted into carbonic oxide in passing through a retort in which cannel-coal is being distilled, so that the resulting gas requires little or no purification; and yet, notwithstanding this reaction, the amount of carbonic oxide in the hydrocarbon-gas is not excessive. The quantity of carbonic acid produced by the combustion of the same bulk of gas obtained by the ordinary process, is greater than with the hydrocarbon-gas, although when such an amount of gas is consumed as is capable of producing an equal light from both kinds, the quantity of carbonic acid formed is somewhat greater in the latter.

The substances condensed by chlorine, bromine, and anhydrous sulphuric acid from illuminating gas, which are the same with each reagent, and to which the illuminating power of the gas is solely due, are found by Dr. Frankland to contain very different proportions of carbon, and to vary in proportion in illuminating power.

The condensable portion from different gases contained quantities of carbon vapour varying from 2.54 volumes to 4.36 volumes, indicating, in gases undergoing the same amount of condensation by chlorine, &c., a difference in illuminating power of more than 71 per cent. This has also been noticed by other experimenters. Dr. Fyfe observed very nearly the same illuminating power in gas from Boghead and Lesmahago cannel, although the condensation by chlorine in the one was 27, and in the other only 17.6 per cent. He conceived that the full value of the former, as an illuminating substance, could not be obtained in consequence of the imperfect methods at present adopted for burning rich gases; but Dr. Frank-

land finds that the 17.6 volumes of hydrocarbon, condensed from Lesmahago cannel-gas, contain as much carbon as the 27 volumes of hydrocarbon condensed from Boghead cannel, and the identity of illuminating power is thus satisfactorily explained. Mr. Leigh considers that the compounds C_8H_8 and C_6H_6 are among these condensed products, both of which must possess high illuminating power. Compounds also probably exist in coal-gas, which are not condensed by any of these agents, but which have great illuminating power, such as the hydride of amyl, $C_{10}H_{11}H$, and others of the series C_nH_{n+2}, of which light carburetted hydrogen C_2H_4, or the hydride of methyl, is the first member.

The condensable hydrocarbons contained in ordinary coal-gas are frequently more highly illuminating than those contained in cannel-gas, as is shown by the following table, where the two are compared; and in the case of the latter the illuminating power is always directly proportional to the amount of olefiant gas to which the per-centage of condensable hydrocarbons is equivalent. The establishment of this rule with regard to gases having such different per-centages of light carburetted hydrogen as the Boghead gas with and without water-gas, Dr. Frankland holds to be conclusive evidence that light carburetted hydrogen has no higher illuminating power than hydrogen or carbonic oxide.

Value of one cubic foot of the olefiant gas contained in the following gases, expressed in sperm candles, each burning 10 hours, at the rate of 120 grains per hour.

CANNEL-GASES.		
Ince Hall Cannel	2.95	candles
Ditto, with water-gas	2.96	„
Boghead Cannel	2.80	„
Ditto, with water-gas	2.86	„
Lesmahago Cannel	2.58	„
Ditto, with water-gas	2.54	„
Ramsay's Newcastle Cannel	2.88	„
Ditto, with water-gas	2.86	„
Methyl Cannel	3.04	„
Ditto, with water-gas	3.03	„
COAL-GASES.		
Pelton Coal	4.23	„
City of London Company's Gas	3.73	„
Gas of the Great Central Company (London)	3.91	„

The condensation test, which has often been taken as a measure of illuminating power, and considered to apply exclusively to the olefiant gas, cannot therefore be depended on. The photometer must always be employed, and the total quantity of oxygen required for combustion, or the quantity of carbonic acid produced by combustion before and after the removal of these heavy hydrocarbons by one of the above reagents, must always be ascertained in order to establish the real value of the gas as an illuminating agent.

Dr. Frankland ascertained that cold had little effect in reducing the illuminating power of the cannel-gases which were diluted with water-gas, but that the highly illuminating cannel-gases themselves suffered a considerable reduction.

The experiments were conducted on several kinds of cannel-coal, both with and without water-gas. The quantity operated upon was 1 cwt., and the heats employed in the retort were low, a certain per-centage of the gas given off during the entire distillation being allowed to collect in a small gas-holder of 80 cubic feet capacity, for examination. A complete analysis of each gas, after passing through lime purifiers, was made in accordance with the foregoing remarks, and the illuminating power of the gases was also estimated by Bunsen's photometer as improved by Messrs. Church and Mann, and the value of the gas calculated in sperm candles burning 120 grains per hour during 10 hours.

The following table shows a summary of the experiments:—

Name of Coal.	Cubic feet of gas per ton.		Illuminating power per ton in sperm candles.		Gain per ton by White's process.		Gain per cent by White's process.	
	By old process.	By White's process.	By old process.	By White's process.	Quantity of gas in cubic feet.	Illuminating power in sperm candles.	Quantity of gas.	Illuminating power.
Wigan Cannel (Ince Hall)	10,900	16,120	4,816	6,448	5,220	1,632	47.9	33.9
Ditto (Balcarres)	10,440	15,500	4,156	5,920	5,060	1,764	48.5	42.4
Boghead Cannel	13,240	36,160	11,340	21,368	24,920	10,038	178.2	88.4
Ditto (2d experiment)	—	51,720	—	20,688	38,480	9,378	290.6	82.4
Lesmahago Cannel	10,620	29,180	7,620	13,934	18,560	6,314	174.8	82.4
Methyl Cannel	9,560	26,400	5,316	11,088	16,840	5,772	176.2	108.6
Newcastle Cannel (Ramsay)	10,800	15,020	5,046	5,646	4,720	600	45.8	11.2

The following table shows the quantity of coal or cannel requisite for producing light equal to 1000 sperm candles, each burning 10 hours, at the rate of 120 grains per hour:—

Name of Coal.	Weight of Coal. By old process.	Weight of Coal. By White's process.
Wigan Cannel (Ince Hall)	465.1	347.4
Ditto (Balcarres)	539.0	378.4
Boghead Cannel	197.5	104.8
Lesmahago Cannel	293.9	160.7
Methyl Cannel	421.4	202.0
Newcastle Cannel	443.9	396.7
Newcastle Coal (Pelton)	745.7	—

The general conclusions from these experiments are summed up by Dr. Frankland as follows:—

1. White's process greatly increases the produce of gas from a given weight of coal or cannel, the increase being from 46 to 290 per cent, according to the nature of the material operated upon.

2. It greatly increases the total illuminating power afforded by a given weight of coal, the increase amounting to from 12 to 108 per cent, being greatest when coals affording highly illuminating gases are used.

3. It diminishes the quantity of tar formed, by converting a portion of it into gases possessing a considerable illuminating power.

4. It enables the illuminating power of highly carbonated cannel-gas to be profitably reduced, so as to be fitted for burning without smoke and loss of light.

5. No additional expense is incurred for the wear and tear of retorts, or in the purification of the gas.

Dr. Fyfe has still more recently experimented upon the hydrocarbon process for making gas in connection with Boghead coal.

He found that produced:—	Boghead Coal alone, average of 6 trials,	Boghead Coal with water, average of 8 trials,
Cubic feet of gas per ton	16,093	39,553
Specific gravity of gas	650	575
Amount condensed by chlorine	22.3	10.89
Illuminating power of 1 cubic foot, in Argand burner of 58 holes, consuming about 4 ft. per hour, expressed in sperm candles, consuming 120 grains per hour	11.79	4.73
1 cubic foot of the gas = grains of sperm	1414.5	568.5
Gas from 1 ton of coal was = to lbs. of sperm	3253.5	3213.5

The value of Boghead gas alone is 34 per cent higher, according to these experiments, than in those of Dr. Frankland, while the total quantity of light per ton of coal expressed in lbs. of sperm from the gas of the hydrocarbon process, differs but little in the two statements, as is shown below :—

	From Boghead Coal alone, lbs. of sperm = gas from 1 ton of coal.	From Boghead Coal, with water-gas, lbs. of sperm = gas from 1 ton of coal.
According to Frankland .	2387.7	3546.5
According to Fyfe . . .	3213.5	3213.54

Mr. Clegg obtained 52,000 cubic feet of gas from a ton of Boghead coal, by the hydrocarbon process, each foot of which gave a light equal to four candles; the total value of the gas in lbs. of sperm was consequently 3515.7. The great difference in the results of the two first-quoted experimenters lies in the different quantities of gas obtained from the Boghead coal alone, differences in the total quantity of gas in the water process being due to the greater or lesser supply of water-gas furnished, the total illuminating power of the gases, whatever their quantity, remaining pretty nearly the same.

Dr. Fyfe accounts for this great difference in the produce from Boghead coal alone, by the low heat at which Dr. Frankland experimented, and quotes an instance in favour of more intense heat, in which he employed a very high temperature, and obtained both a larger produce of gas, and a gas of superior illuminating power; a ton of coal yielding 17,680 cubic feet of gas, equal to 12.12 candles per foot, or 3673 lbs. of sperm per ton of coal,—a quantity greater even than was obtained by Frankland by the hydrocarbon process.

Dr. Fyfe, from the foregoing results, considers that by employing the water process "*there is no increase in light from the gas of a ton of coal compared with that obtained in those instances in which the carbonizing of the coal alone is properly conducted.*"

His next inquiry was directed to the question, whether there may not be a gain by obtaining a much larger quantity of gas, though it be of inferior illuminating power.

With this object, smaller quantities of coal were operated upon in the same apparatus, and a large quantity of water-gas introduced at a high temperature into the coal retort.

An average of 5 trials gave :

Cubic feet of gas per ton of coal . .	52,042
Specific gravity of gas	462
Condensed by chlorine per cent . .	5.8
Illuminating power per foot in Argand burner, consuming about 8 feet per hour, in sperm candles of 120 grains per hour's consumption	1.99
1 cubic foot of gas = grains of sperm .	238.56
Gas per ton of coal = grains of sperm .	1773.6

Judging from these experiments there is a very great loss of total illuminating power by the use of water-gas, amounting on the average to 46 per cent ; while Dr. Frankland, assuming a low value for the gas from Boghead coal alone, calculated the gain in illuminating power by water-gas at 48 per cent.

In another experiment in which Dr. Fyfe obtained 75,253 cubic feet of gas from a ton of coal with water-gas, the gas obtained was only equal in illuminating value to 348.3 lbs. of sperm. The gas obtained in this experiment was only equal to 0.27 candles per cubic foot, while Mr. Clegg obtained 75,000 cubic feet in the same manner, of the value of 2.4 candles per cubic foot.

Thus, the most discordant results are obtained by different experimenters, and the process must be considered as very uncertain. Dr. Fyfe distinctly announces the conclusion he arrived at from his trials, in the following terms :—"*In no instance is there any gain in the amount of light from Boghead coal-gas by the agency of water, in the method recommended by the advocates of the hydrocarbon-gas ;*" and whenever the quantity of gas is increased to any great extent, there is a very decided loss of illuminating power.

In estimating the economy of the hydrocarbon process, and considering the total quantity of light obtainable from a ton of coal as the standard of comparison, Dr. Fyfe arrived at the following results, taking his own experiments as to the quantity and quality of the gases generated, and Mr. Clegg's estimate of the cost of manufacturing the coal-, water-, and hydrocarbon-gases, as correct. Mr. Clegg being a stanch advocate of the hydrocarbon process, has probably not over-estimated the cost of production ; indeed, in the case of water-gas alone, many incline to think that five pence per 1000 cubic feet, the cost assumed, is far too low.

Boghead coal, yielding 16,093 cubic feet of gas, and costing 28s. per ton, and the manufacturing expenses, according to Clegg, being 143.775 pence per ton.

16,093 cubic feet of coal-gas, yielding light equal to 3253.5 lbs. of sperm, will cost 479.775 pence.

39,553 cubic feet of hydrocarbon-gas, yielding light equal to 3213.5 lbs. of sperm, will cost 597.075 pence.

Or, 1000 cubic feet of coal-gas cost 29.804 pence.
1000 „ „ hydrocarbon-gas 15.09 „

Then,

lbs. of sperm per ton of coal.		lbs. of sperm per ton of hydrocarbon.		Cost of coal-gas per ton.		Comparative cost of coal-gas.	
3253.5	:	3213.5	=	479.77	:	473·87	and
597	:	473.87	=	100	to	79.3	

or a saving in favour of Boghead coal-gas alone = 20.7 per cent.

When more gas is obtained from the same quantity of coal by the still greater addition of water-gas, the comparative economy of the two processes is observed to be still less favourable to the water scheme. Then, as before,

		Pence.
1 ton of coal yielding	16,093 cubic feet at a total cost of	479.775
Water-gas . .	35,950 „ „ „ „	179.752
	or 5d. per 1000 cubic feet.	
Hydrocarbon-gas .	52,042 cubic feet at a total cost of	659.527
	or 12.672 pence per 1000 feet.	

1 foot of the gas being equal to 1.99 candles, or 1773.6 lbs. of sperm per ton of coal, we obtain—

Coal-gas =lbs. sperm per ton.		Coal- and water-gas =lbs. sperm per ton.		Cost of coal-gas.		Comparative value of coal and water.	
3253.5	:	1773.6	=	479.77	:	261.5	and
659	:	261.5	=	100	:	39.6	

showing a saving in favour of Boghead gas alone of 60.4 per cent.

It has been further shown by Dr. Fyfe that in many of the published statements which have been put forward in favour of this mode of gas-manufacture, the advantages arising from the quantity of gas alone have been taken into calculation, without reference to its inferior quality, and that in every case where a fair quantity of gas has been obtained from the coal alone by proper management, not only is there no economy in converting it into

hydrocarbon-gas, but a considerable loss, and this without taking enlarged gas-holders, pipes, &c., into account, which would be required to obtain an equal amount of light from the less luminous gas.

The foregoing trials having been made in small apparatus, Dr. Fyfe has since experimented on a manufacturing scale at Leith Gas-works, where, although the results did not perfectly correspond with those previously obtained, the general conclusions were confirmed. He obtained 27,700 cubic feet by the hydrocarbon process from a ton of coal, which was equal to 2830.15 lbs. of sperm. Dr. Frankland, without reference to the economic value of White's process, the details of which he leaves in the hands of gas-engineers, maintains that in the comparisons instituted by Dr. Fyfe, the quantity of gas obtained from Boghead coal alone is very much over-estimated, and hence the great discrepancy in their conclusions regarding the merits of the process. In corroboration of this view he cites a former estimate of the quantity of gas yielded by a ton of Boghead coal by Dr. Fyfe, and others by eminent gas-engineers who worked upon a manufacturing scale, with some others by himself, in which a diaphragm retort was employed. The following table shows these different results:—

ESTIMATES OF THE VALUE OF BOGHEAD CANNEL.

Authority.	Cubic feet of gas per ton.	Gas from 1 ton = lbs. of sperm.
Mr. Wright	11,000	2182.1 lbs.
Mr. Barlow	13,344	2057.0 „
Mr. King	13,549	1993.6 „
Dr. Fyfe	14,800	2283.2 „
Advertisement of Proprietors of Boghead Cannel	13,500	1967.1 „
Dr. Frankland, 1st experiment	13,240	2387.7 „
Dr. Frankland, 2d experiment	14,560	2441.1 „
Dr. Fyfe, with 7 lb. charges	16,093	3253.5 „

Comparing these results, including the lower estimate of Dr. Fyfe for the Boghead gas alone, with the gas from the hydrocarbon process, examined by the Bunsen photometer, in three several trials, Dr. Frankland shows the following amounts of gain by that process, according as one or other of the authorities for the Boghead gas alone be selected.

PER-CENTAGE GAIN IN ILLUMINATING POWER BY THE HYDROCARBON PROCESS AS APPLIED TO BOGHEAD CANNEL.

Name of Experimenter on hydrocarbon process.	Comparison with results obtained with Boghead Cannel alone, by						
	Mr. Wright.	Mr. King.	Dr. Fyfe.	Mr. Barlow.	Proprietors of Boghead.	Dr. Frankland, 1st Expt.	Dr. Frankland, 2d Expt.
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Dr. Fyfe, experiment at Leith Gas-works	29.7	42.0	24.0	37.6	43.9	18.5	15.9
Dr. Frankland, 1st experiment.....	89.6	107.5	81.2	101.1	110.3	73.3	69.5
Ditto, 2d experiment	105.6	125.0	96.5	118.1	128.1	87.9	83.8
Ditto, 3d experiment	127.7	149.2	117.6	141.5	152.6	108.1	103.6

It thus appears that there is a large gain of illuminating power by the judicious use of water-gas, varying with the quantity of water-gas used; and Dr. Frankland considers that in the last experiments of Dr. Fyfe far too little water-gas was employed, hence its action was not fairly tested.

Mr. Barlow has since endeavoured to ascertain the relative amount of water-gas capable of being produced by charcoal and coke alone, and in connection with the production of gas from cannel-coal. The apparatus with which he worked at one of the mills where White's hydrocarbon process has been introduced, appears to have been very defective, and many of the conclusions he draws are, therefore, the result of calculation.

In order to ascertain the amount produced per hour, and the composition of the water-gas, four cylindrical retorts were first filled with charcoal, and being heated to a bright red heat, steam was admitted from a boiler. During the first five hours the production of gas amounted to 605 feet per hour, but declined afterwards in consequence of the retorts cooling, the bad arrangements of the furnace, and inferior fuel, to 352 cubic feet per hour for 16 hours. The average quantity obtained during a day's work was 331 feet per working hour.

The gas consisted of—

Carbonic acid . . .	20
Carbonic oxide . . .	20
Hydrogen	60
	100

Had the carbonic acid been absorbed by purification, the result of a day's operation would have been—

Hydrogen . . .	5600
Carbonic oxide . .	1866
	7466 purified water-gas.

When Newcastle Pelaw Main coke was employed instead of charcoal in the retorts, the gas was of the same average composition, excepting the addition of about 3 per cent of sulphuretted hydrogen.

The total purified water-gas amounted to—

Hydrogen . . .	3713	cubic feet.
Carbonic oxide . . .	1238	„ „
	4951	„ „

or 225 cubic feet per hour. The coke was, consequently, not so well adapted to the process as charcoal.

Hydrocarbon gas was then made from 56 lb. charges of Boghead, cannel, and charcoal, the gas being purified by lime. In calculating the relative quantities of gas in the mixture thus obtained, the gas from the cannel itself is estimated on an average of 12,800 cubic feet per ton, which proportional quantity being deducted from the total quantity of gas made, gave the amount of water-gas with which the cannel-gas was mixed.

The proportion of cannel-gas to purified water-gas was then as 100 : 97, and the average yield of purified water-gas was reduced to 140 cubic feet per working hour.

The gas obtained from 4 cwt. of Boghead, cannel, and water, amounting to 5304 cubic feet, was allowed to stand for four hours in the holder. It then contained 14 per cent of hydrocarbons condensed by bromine, and 7 per cent of carbonic acid which had escaped the lime-purifiers. Its illuminating power compared with standard sperm candles was found equal to 1573 lbs. of sperm per ton of coal used, which, when compared with the average of 2057 lbs. of sperm from Boghead cannel alone (as the result of Mr. Barlow's experience), showed a loss of 24 per cent of illuminating matter, the amount of mixed gas produced being 26,520 cubic feet per ton of cannel.

This loss of illuminating power was found to be due to the carbonic acid contained in the gas, and to this cause, or imperfect

purification, Mr. Barlow attributes the want of accordance in the results of other experimenters on the hydrocarbon-gas.

By passing the gas through another purifier, the 7 per cent of carbonic acid was reduced ¾ per cent, and the illuminating power rose at once from 17.3 to 35 candles, or the removal of 6¼ per cent of carbonic acid from the mixed gas doubled its illuminating power. The total illuminating power of the gas from a ton of cannel by the hydrocarbon process was thus raised to 2842 lbs. of sperm, and a gain of 38 per cent established over the gas produced in the ordinary manner.

Hydrocarbon-gas prepared from charges of 84 lbs. and 112 lbs. of Newcastle cannel and charcoal, the gas being purified by lime, was obtained at the rate of 29,180 cubic feet per ton of coal.

The proportion of cannel-gas to purified water-gas was as 100 : 205, the average yield of Newcastle cannel taken at 8500 cubic feet per ton, and the average quantity of purified water-gas per working hour being 292 feet.

This gas contained 4.25 per cent condensable by bromine, 11 per cent of carbonic acid, without any sulphuretted hydrogen or ammonia.

Burned without special purification, it yielded light equal to 186 lbs. of sperm per ton of coal, while Newcastle cannel alone yields, on an average, light equal to 851 lbs. of sperm per ton of coal, showing a loss of illuminating matter to the extent of 78 per cent.

When perfectly purified from carbonic acid, however, it yielded light equal to 1125 lbs. of sperm, thus showing a gain of 32 per cent of illuminating matter.

In order to test the opinion thrown out by Dr. Frankland, that the carbonic acid produced in the water retorts was converted into carbonic oxide in passing through the cannel-coal retort, no lime was employed to purify the hydrocarbon-gas from 112 lb. charges of Newcastle cannel and its own coke, but oxide of iron was used instead, which having no action upon carbonic acid, is said to absorb the heavy hydrocarbons. The following results were obtained:—

Gas per ton of cannel . .	23.384 feet.
Hydrocarbons condensed by bromine	5.5 per cent.
Carbonic acid . . .	12.5 „
Value of illuminating matter	182 lbs. of sperm per ton of coal.
Loss in illuminating matter	79 per cent.

THE SAME GAS PURIFIED FROM CARBONIC ACID.

Gas per ton of cannel .	. 20,459 cubic feet.
Value of illuminating matter	. 931 lbs. of sperm.
Gain in illuminating matter	. 9½ per cent.

The proportion of cannel-gas to purified water-gas was here 100 : 94. The yield of purified water-gas was at the rate of 143 feet per working hour. The carbonic acid generated amounted to 26¾ per cent, and the water-gas containing itself, on an average by former experiments, 20 per cent, the difference may be fairly attributed to the cannel-coal, whence it is inferred that no carbonic acid is converted into carbonic oxide in the coal retort. The greatly diminished illuminating power in the gas from this experiment is attributed to the oxide of iron used for purification absorbing much of the heavy hydrocarbons.

The chief difficulties to the introduction of this process of gas-making are therefore shown to consist in the uncertain rate of production of the water-gas, and consequent unequal proportion of cannel to water-gas, and the large quantity of carbonic acid which requires to be removed by the purifiers.

Mr. Barlow is of opinion that it will be found absolutely necessary to collect and purify the water-gas in a separate gas-holder, from which a regulated supply can be admitted to the coal retorts, varying at different periods of the process and according to the nature of the coal employed.

The cost of purifying the water-gas from carbonic acid alone he estimates at 4d. to 3d. per 1000 cubic feet of the crude gas, and considers that passing the gas after cooling through a retort containing red-hot coke will be found most practicable. Although the gain in illuminating matter with many kinds of cannel-coal which bear great dilution may amount to 50 per cent, it is not considered probable that the process will be able to compete with the old process in localities where coke and tar return 50 per cent of the prime cost of the coal used. Thus taking, according to Mr. Barlow's estimate, the London prices for coal and coke in July 1854, the following figures show the comparative cost of the materials for manufacturing gas equal to 13 candles (per 5 feet burnt per hour), on the two systems :—

COST OF NEWCASTLE COMMON COAL-GAS.

1 ton of coal delivered		17	0
9 bushels of coke as fuel, at 3½d. . .		2	7½
Purification of 900 feet of gas, at ¾d. .		0	6¾
		20	2¼
Deduct—			
36 bushels of coke at 3½d. . . 10 6			
10 gallons of tar at ¾d. . . 0 7½	—11		1½
Cost of materials for making 900 feet of gas		9	0¾

Or a fraction more than 1s. per 1000 cubic feet.

NEWCASTLE CANNEL HYDROCARBON-GAS.

6 water retorts producing 600 feet per hour	14,400	
2 retorts carbonizing 11½ cwt. of Newcastle cannel	4,887	
	19,287 ft.	per diem.

Cost.		
11½ cwt. of Newcastle cannel at 25s. .	14	4½
The coke produced will serve as fuel, with 5½ cwt. of coal at 16s. . . .	4	3½
Purification of 19,287 feet at ½d. . .	0	9¾
	19	5¾
Deduct 8 gallons of tar at 1d. . .	0	8
Cost of materials for making 19,287 feet of gas	18	9¾

Or $11\frac{7}{10}$d. per 1000 cubic feet.

BOGHEAD CANNEL HYDROCARBON-GAS.

8 water retorts producing 800 feet per hour	19,200 feet.	
1 retort carbonizing 4½ cwt. of Boghead cannel	2,812	
	22,012 ft.	per diem.

4½ cwt. of Boghead cannel at 40s. . .	9	0
Fuel 1188 lb. for water retorts		
„ 156 „ for cannel retort		
Carbon 396 „ for decomposing water		
1740 „ = 15 cwt. 2 qr. 24 lb., or 4½ bushels of coke at 3½d.	12	1¼
Purification of 22,012 feet of gas at ½d. .	0	11
	22	0¼
Deduct 6 gallons of tar at 1½d. . .	0	9
Cost of materials for producing 22,012 ft. of gas	21	3¼

Or $11\frac{3}{10}$d. per 1000 cubic feet.

No great economy can therefore be expected from the process in London and similar localities, where the secondary products are of great value, while in places where fuel is cheap, and coke is comparatively valueless, the process may prove highly remunerative. The above calculations, however, are based upon certain improvements to be made in the apparatus, which shall effect

1. A constant temperature of not less than 1500° F. in the water retorts, and an expenditure of fuel equal to 60 lbs. for 1000 cubic feet of water-gas.

2. The conversion of the carbonic acid produced in the water retort into carbonic oxide before its introduction into the cannel retort.

3. The supply of the water-gas in such proportions as shall produce uniformity in the quality of the mixed gases.

Webster has obtained a patent for a similar process to that of White. The Messrs. Kirkham have proposed to use hydrogen and carbonic oxide obtained from the decomposition of water for heating purposes, and to naphthalize it for the generation of light. This process was about to be adopted in Paris, when it was interdicted in consequence of the gas being without smell, which, in the event of an escape from the mains or delivery-pipes, would elude detection, and the large proportion of carbonic oxide it contained might prove fatal to the consumer before he was made aware of its presence.

Gillard proposes to render water-gas luminous, which has been prepared as above, by burning it in contact with a solid substance, such as metallic platinum, which, in the form of a wire-work cap, being heated to whiteness by the flame, evolves light. The absence of smell, and consequently of the warning against danger, applies here with equal force, while the illuminating power is not so great.

In connection with these methods of obtaining gas, we may lastly notice a form of double retort, patented by Messrs. Laming and Evans, for distilling oil, resin, tar, and other similar substances, in the lower part of which coal may be placed, while coke occupies a horizontal shelf, or second chamber, above the coal. The oil or melted resin is allowed to fall upon the red-hot coke on the upper shelf, and the gases and tar thus generated are obliged to traverse the coal or coke in the lower part before escaping to the hydraulic main. The liquids to be distilled are supplied by a syphon-pipe, delivering into a wide inverted funnel above the coke in the upper part of the retort.

Naphthalized Gas.—The illuminating power of gas is very much increased by the presence of volatile hydrocarbons, and many years ago Mr. Lowe introduced, or rather proposed, a plan for saturating inferior qualities or ordinary coal-gas with naphtha or the spirit distilled from coal-tar, and thus augmenting its illuminating power nearly one-half. The remarkable increase of light, however, produced by naphthalized gas, frightened the gas companies, who foresaw nothing but ruin in the diminished quantity of gas which would necessarily be consumed for the production of an equal amount of light. Cold water was consequently thrown upon the project, and the invention has only been of benefit to individuals, and not to the public at large, which might have been the case had it been introduced upon a large scale.

Another objection to the introduction of naphthalized gas into private houses was raised by the insurance companies, the use of so inflammable a substance as naphtha being considered dangerous under any circumstances; but this objection no longer applies, as naphtha and camphine, a still more inflammable body, are consumed in lamps in a manner much more liable to give rise to accidents than that proposed by Mr. Lowe. The original plan

FIG. 370.

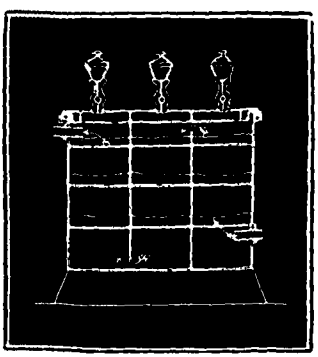
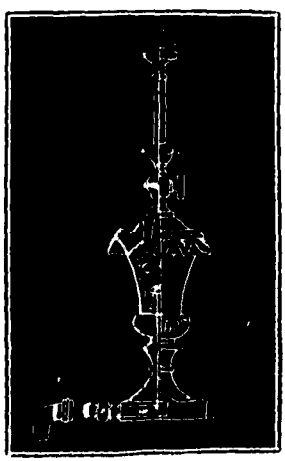


FIG. 371.



was to fill the ordinary wet gas-meter with purified naphtha, which was kept filled to the same height from a reservoir in connection with it, upon the principle of the common bird fountain. The gas was thus measured and saturated with naphtha at the same

time. As danger was apprehended, however, from the large quantity of naphtha necessarily contained in the meter, a box with a lid closed by a water-valve was substituted. This box was supplied with shelves, and separated into partitions, as shown in Fig. 370, and naphtha was poured upon the shelves from the funnels above in small quantities at a time, or sponges were saturated with it and laid upon the shelves. The box was inserted at any convenient locality in the circuit of the supply-pipe, and the gas forced to traverse the different partitions of the box in the manner represented by the arrows in Fig. 370. The box may also be replaced by an ornamental metallic vase, containing a sponge filled with naphtha, and connected with the gas-pipe in the manner represented in Fig. 371. The advantages attending the use of naphthalized gas are not confined to the increased intensity and brilliancy of the flame, and the consequent diminution of the quantity of gas required for the production of an equal amount of light, but less heat is said to be generated by the combustion of naphthalized gas as compared with coal-gas, affording an equal intensity of light. It has been assumed that in ordinary cases the heating power of common coal-gas is to that of naphthalized gas in the ratio of about four to three for equal quantities of light. Naphthalized gas is consequently preferable to common coal-gas for lighting ill-ventilated or crowded localities, and particularly during the summer season, when the external temperature is high. The light produced by the flame of naphthalized gas is also found to be more analogous to that of the sun; hence objects illuminated by it,—as pictures, scenery, the face, &c.,—appear more in their natural colours, and the human face, in particular, does not assume the pallid hue which is peculiar to it when illumined by a flame of ordinary coal-gas. Inferior kinds of gas, containing a lesser proportion of carbon, such as are evolved from coke furnaces, where the object of the manufacture is to retain as much carbon as possible in the coke, when charged with different hydrocarbons, become converted into illuminating gas of as good, if not better, quality than that obtained from ordinary coal. Some alterations in the construction of the burners may be necessary for consuming gas highly impregnated with naphtha; and there is, perhaps, danger of the naphtha being condensed and deposited in the pipes, particularly if the gas be over-saturated with the vapour; but there appears little reason to doubt that these difficulties, and particularly that arising from the condensation of the naphtha, would

be overcome if other circumstances were favourable to carrying out the project.

Portable Gas.—The distribution of gas by pipes is exceedingly expensive, both as regards laying them down and the cost of repairs, and is also attended with the inconvenience that the light cannot, as with candles and lamps, be carried to any particular spot. Even the joints in the arms of the burners, as they are sometimes used, only admit of a short circular motion in a very limited space. Two inventions have at times been employed in some localities to meet this difficulty, although they have never come into general use in this country.

Compressed Gas.—The first, and older of the two, is the use of compressed gas. Gas was forced into small vessels, contained in the foot of lamp-like burners, which should contain sufficient gas for several hours' consumption. Oil-gas, on account of its greater illuminating power, is decidedly preferable for this purpose, for ½ a volume will produce as much light as 1 volume of coal-gas. It has been ascertained that an ordinary burner consumes 1 cubic foot of oil-gas in the hour; for a single evening, therefore, about 8 cubic feet would be required, and these must be compressed into the space of a ¼ cubic foot—the largest space that can be allowed for the foot of a lamp—which would require the enormous pressure of 32 atmospheres at ordinary temperatures, and a much greater pressure at temperatures slightly higher. The vessels of these gas-lamps must, therefore, be constructed to resist, at least, double this pressure. The diminution of illuminating power by the condensation of the carbo-hydrogens, as well as the danger of explosion, have prevented the adoption of this plan. There is also great difficulty in obtaining a uniform flow of gas, as the pressure in the vessel diminishes with the consumption.

Portable Uncompressed Gas.—Another method, which, however, does not answer the same purpose as the foregoing, was introduced by Houzeau-Muiron, at Rheims, and for some time adopted at Amiens, Rouen, and Paris. The distribution of the gas within the houses remaining the same—the burners and the flame, therefore, being immovable—Muiron has endeavoured to avoid the grand expense of conducting mains. He employs very large vans, or rather, very large cases of light sheet metal upon wheels, in which are placed wide bags of gas-tight varnished material. Two valves opening in opposite directions serve for the entrance and egress of the gas. The bag is first pressed together, to force out the air,

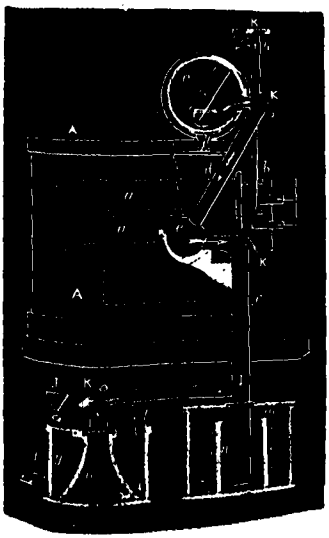
and the filling-tube is screwed into the mouth of the proper valve. This tube is attached to the gasometer at the works, which has only to be lowered to fill the bag with gas, which then of course closes the valve by which it had entered. The van is then driven to the house of the consumer, in whose cellar there must be a small gasometer constructed of sheet zinc inverted in a wooden cistern, and supplied with a filling tube, which is now connected with the exit valve of the bag. The two flat wooden ends of the cylindrical bag are then drawn together by means of strings; the bag is thus emptied, and the gas forced through the tube into the gas-holder, from whence by leaden pipes it may be carried forward to the burners. The filling, as here described, is similar to the mode of conveying wine in leather pouches. The small gasometers are so simple that they do not cost more than about three pounds. The bags contain from 200 to 1000 cubic feet of gas. The first time that they are filled, the bags may possibly retain a little air in the folds, which is afterwards expelled by the gas.

Gas from Soap-water.—A favourable idea of the practical value of chemical knowledge is afforded by the process carried out at the works of Houzeau Muiron, at Rheims, where very good gas and a handsome profit are obtained from a substance, the riddance from which had previously been a source of expense to the manufacturer. This refuse is the soap-water in which woollen stuffs have been freed from fat. Besides the unchanged fat with which the goods are charged as they come from the loom, the soap-water contains a solution of oleate and stearate of soda, and compounds of the same acids with lime in suspended flakes, and lastly, animal matter extracted from the wool. From all parts of the town the soap-water is collected, and brought to the reservoirs of the works, where 300 cwts. at a time are treated with 2 per cent of sulphuric acid, or twice as much hydrochloric acid, mixed with an equal quantity of water. After the lapse of 12 or 18 hours, the water is found to contain Glauber's salt or sulphate of soda in solution, a little gypsum being formed at the same time, while an impure grey fatty matter rises to the surface. This consists of the fatty acids, oil, and animal matter mixed with water, the greater part of which having already been mechanically separated, the remainder is removed by melting the fat in a copper vessel, and ultimately drawing it off into a second boiler containing some sulphuric acid, for clarification. The filtration which follows affords a clear oil, and this gives with crude soda (containing sulphuret of sodium) a very

tolerable soap, whilst sulphuret of iron separates, leaving a black solid residue containing much fat for distillation in the gas retorts. The process of distillation is similar to that practised with resin: the tar produced the first day is used on the morrow to dissolve and liquify the solid residue. The soap-water is obtained at the rate of about 9 pence for every 30 gallons.

Gas from Animal Matter.—In the distillation of animal matters, bones, flesh, &c., which has long been practised for the production of bone-charcoal and bone-black, a tar containing Dippel's animal oil, and gases, are generated. The illuminating power of the latter has latterly attracted the attention of manufacturers. Seguin, in particular, has carried on the process on a large scale, making use of the gases. When the flesh of dead animals, which contains 60 per cent of water, is employed, the latter must be removed by drying before the material is placed in the retorts, which are kept at a cherry-red heat. The sulphur (a constituent of albumen, fibrine, &c.) is chiefly found in the gas as sulphuret of carbon, the nitrogen of the flesh as carbonate of ammonia. After being properly cooled, the gas is first passed through a solution of chloride of calcium, where carbonate of lime and sal-ammoniac are formed, and from thence through pipes containing lumps of sulphur, which condense the sulphuret of carbon to the liquid state. The latter would be converted in the flame into sulphurous acid and carbonic oxide.

FIG. 372.



Gas from Wood and Turf.—Wood and turf are not well adapted to yield gas for illuminating purposes, but where coal cannot be had, or only at a very high price, the illuminating power of the gases evolved from these substances may be increased by passing them through vessels containing naphtha or oil of turpentine. An apparatus used in Moscow for this purpose is shown in Fig. 372. *aa* are the retorts containing the wood; the gaseous products and tar pass into the hydraulic main *c*, the gases then pass into a ball *e*, heated to a dull red heat in the

furnace, and thence into a vessel *g* containing naphtha, through which it is obliged to force a passage; the vessel *n* receives the liquid products. No purification is required for this process, but the illuminating power must altogether depend upon the volatility of the naphtha.

We are not able to state whether the wood-gas introduced into many German towns by Dr. Pettenkofer, of Munich, is prepared in a similar manner, and rendered luminous by naphtha; but the account of its high illuminating power, published by Professors Steinheil and Liebig, would lead us to believe that some highly carbonated vapour must be incorporated with it. The wood employed must be thoroughly dry, and is baked on the top of the ovens before it is introduced into the retorts. Different kinds of ordinary firewood may be employed, provided they are all perfectly dried, and the gas is carried through a red-hot pipe, situated in the furnace, before it enters the dry lime-purifier.

The mean results obtained by Messrs. Liebig and Steinheil, in comparing the wood-gas made at Bayreuth with the coal-gas of Munich, were as follows:—

Expressed in English standard sperm candles, and with a consumption of 4½ cubic feet per hour,

Wood-gas was equal to .	.	17.23 candles
Coal-gas „ „ .	.	14.45 „

No appreciable diminution of illuminating power was observed after passing the gas through 10,000 feet of pipe.

The wood-gas is somewhat more costly than coal-gas, but its greater illuminating power is represented as more than compensating the difference of price.

The following relative amounts of consumption, illuminating power, and cost of coal- and wood-gas in Germany, are given by M. Riedinger, the engineer engaged in erecting the works for wood-gas:—

Standard-candles	5.	10.	14.	16.	18.
Equal to cubic feet of Munich coal-gas.....	2.55	4.08	5.01	5.90	6.66
„ „ cubic feet of wood-gas at Coburg ...	1.70	2.70	3.70	3.97	4.30
The cost of coal-gas in Munich being 12s., and of wood-gas in Coburg 14s. per 1000 cubic feet, the cost of the same amount of light would be cheaper when obtained from wood in the following ratio: .....per cent	24	23	17	22	25

Lowe obtained a patent in 1845 for saturating previously dried

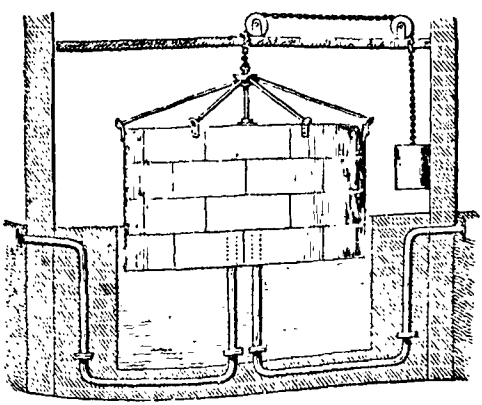
peat or turf bricks with pitch, tar, or resin, at a high temperature, and employing the bricks thus prepared for generating gas in conjunction with steam, heated to a high temperature by passing through red-hot pipes after leaving the generating boiler.

Messrs. Pauwels and Dubochet patented a process in 1850 for making gas and superior coke, adapted for locomotive and boiler fires, in one operation. The process of the patentees consists in heating the coal, in close ovens, by fires below, pumping off the gases at certain periods of the operation by exhausters, and subsequently heating the coke to a higher temperature. The arrangement of apparatus is such, that the gas which escapes at the first and last periods of the process can be excluded altogether from mixing with those portions that are adapted for illumination, and being conveyed to the furnaces below the ovens, assists in heating the flues which surround them.

Collection and Distribution of Gas.—Before entering the vessels employed for storing, the gas is usually passed through a meter, or measuring apparatus, as a check upon the total amount of production. The construction of this apparatus is similar to that employed for measuring the gas supplied to each consumer, and will be described below. A time-piece, and a mechanical contrivance called a *tell-tale,* are generally attached to the station-meter, which detects any irregularities in the hourly production of gas.

Gas-holder or Gasometer.—The production of gas, and its consumption, do not go hand-in-hand, the gas not being consumed at the same time, nor in the same quantity, as it is evolved from the retorts; the primary pressure in the latter would also be too strong and too variable for the production of steady gas flames. Large inverted cylindrical vessels are employed for storing the gas, which are open at bottom, and dip into water: while acting as repositories for the gas, these vessels also serve to force the gas onward with the

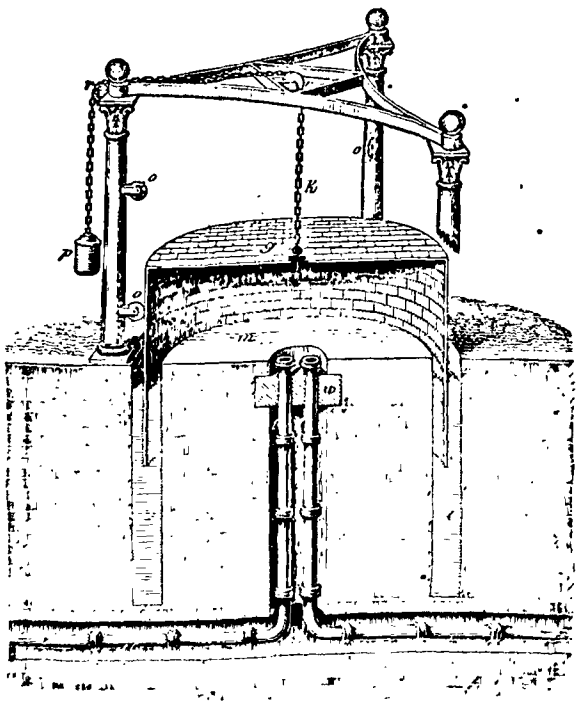
FIG. 373.



precise amount of pressure necessary for producing a proper flame at the burners. These repositories are very improperly called *gasometers*. In Fig. 373, the different parts may be easily distinguished. The flat cylindrical vessel is suspended by means of a chain from the top, which passes over two pulleys on the beam above, and is attached at the other end to a counterpoise. The lower open end dips into a reservoir of water, into which also the pipes open for the entrance and egress of the gas. There are practical difficulties attending this mode of suspension, with larger gas-holders the beam not being able to sustain the weight without bending, and the large quantity of water becoming a source of much inconvenience, particularly in cold weather, when steam requires to be blown into it to prevent freezing. In this case the arrangement shown in Fig. 374 has sometimes been adopted. The gasometer *g* is a large drum of sheet-iron, rivetted together in the manner of a steam-boiler. Several coatings of tar, put on hot on both sides, are sufficient, notwithstanding the number of rivets, to make it quite gas-tight. Instead of being sunk in an entire basin, the gasometer *g* works in a ring-shaped space *i i*, surrounded by brickwork. The entrance and exit pipes *t t'* for the gas are generally carried up a central channel in the pillar of brickwork *m*; they might be brought up through *i*, but not so conveniently. This channel *v* is closed at *w* to prevent the escape of the gas. The sides of *i* are covered with cement, which renders them quite water-tight. The drum is suspended from its centre by the chain *K*, the rollers *r r* being fixed upon the triangular (cast-iron) frame: *p* is the counterpoise. To prevent all lateral motion, the iron drum *g* is moved up and down against the guiding rollers *o o o*. A layer of tar is poured upon the surface of the water in *i*, to prevent the frequent renewal, which would otherwise be necessary, on account of the constant evaporation which takes place with each addition of gas. It is sometimes cheaper, although much less commodious, and more space is required, to construct the water cistern of cast-iron plates instead of brickwork; the whole then stands above the ground, and admits of being easily repaired, while the lasting value of the materials compensates for their less durable character. Very large gasometers are suspended without framework, and the counterpoise, instead of being on the outside, is brought into the middle of the apparatus. In the centre of the drum a wide pipe, open at both ends, is attached to the top, so that the whole forms a kind of (very thick) ring; a second, somewhat smaller pipe, passes up from the

bottom of the water cistern, and with it three strong iron rods with pulleys. This last fixed tube, with the three rods, is stationary, while the gasometer moves freely up and down. Three chains pass over the pulleys, and support the counterpoise which moves in the

FIG. 374.



interior of the fixed pipe. In large gas-works a number of medium gasometers are preferred to a very large one, although they are more expensive. In order to store a large quantity of gas in a small superficial space, Tait proposed what is called the telescope gas-holder, which consists of 2, 3, 4, or more cylinders placed one within the other, like the separate limbs of a telescope, the outermost of which only is closed at the top, and all are contained in a single water-tank. The upper edge of each of the lower cylinders has a broad flange turning downwards on the inside, while the lower edge of the inner cylinders is turned upwards and towards the outside. When the gas enters, the inner drum first ascends, and having arrived at its greatest height, raises the next, by means

of its flange catching the flange of the second, while both having been immersed in water, the flange itself becomes filled, forming a water-lute, and preventing the escape of the gas.

With reference to the shape of the gas-holders, cylinders, with a radius equal to their height, are most economical; as vessels of these dimensions contain most gas with the least amount of material in their construction. A foot, however, is added to the height, that the margin may always be under water. The capacity, and consequently the diameter, or the height of the gasometer, must depend upon the demand for gas; if the cylinder, at its extreme height, is to contain q cubic feet of gas, then r being = the radius, and h = the height,

$$3.14\ r^2\ h = q$$

therefore: when $r = h$

$$3.14\ r^3 = q$$

and hence $$r = \sqrt[3]{\frac{q}{3.14}}$$

On filling the gas-holder, the tube t is closed, and the gas flowing from t' soon begins to raise it, its weight being balanced by p, and the weight of the cylinder, together with that of the gas, being much less than the weight of an equal volume of water. A gas-holder 40 feet in diameter (and consequently 21 feet high), when at its greatest height, weighs, gas and iron together, about 123 cwt., while an equal volume of water would weigh 7,800 cwt. As soon as the cylinder is filled up to the height of its radius, t' is closed, and the connection between the gas-holder and the retorts is thus cut off. The next object is to cause the cylinder to sink in such a manner that the gas shall flow out with a certain degree of force, and which generally corresponds with the pressure of a column of water of from 1 to 2 inches high; the water on the outside of the cylinder must, therefore, stand from 1 to 2 inches higher than on the inside. A water-gauge, or manometer, is connected with the outflow pipe to show this relative level, or the amount of pressure exerted by the gas-holder upon its contents; and the counterpoise is altered until a difference of level, amounting to 1 or 2 inches, is indicated. From obvious reasons, however, this pressure cannot long remain constant. The cylinder being immersed in water loses as it descends more and more of its weight, the loss being equal to the weight of the water displaced by the portion immersed; the effect is, therefore, the same as would result from a gradual increase in the weight of the counterpoise: the pressure is dimi-

nished. With a drum of the above dimensions, the cubic space occupied by 10 feet of the margin would be nearly 30 cubic feet, which, therefore, displace 30 cubic feet = 927 lbs. of water, and the pressure would be diminished $\frac{1}{6}$th inch when it was half immersed. This diminution of pressure may be counteracted by the chain, when constructed in a particular manner. In every position of the chain, one portion on the side of the counterpoise will balance another portion on the other side of the pulleys. The lower the cylinder sinks, the more of the chain passes to its side of the pulley; each link, however, is a weight taken from the counterpoise and added to that of the cylinder, so that this is increased in weight by twice the weight of chain which has passed the pulley. The weight of the chain must, therefore, be such that the portion passing the pulley weighs just half as much as the water which is displaced at the same time.

It is obvious that the specific gravity of the gas must also have an effect upon the working of the gas-holder. Oil-gas has nearly the same density as the air, and the weight of the enclosed gas is, therefore, not sensibly different from that of an equal volume of air; it will, consequently, be in equilibrium with the external air. This is not the case with coal-gas, which is $1\frac{3}{4}$ times lighter. That portion of the gas-holder which is above the water is, consequently, in the condition of an air-balloon, the enclosed gas being lighter than the same number of cubic feet of air. If this difference in the gravities were greater than the weight of the iron composing the vessel, then the gasometer would rise; under existing circumstances, its tendency to rise merely diminishes its weight. A cylinder 40 feet in diameter, and 20 feet at its highest stand, contains 25,231 cubic feet of coal-gas; the same number of cubic feet of air will weigh 1020 lbs., while the gas will only weigh 662 lbs.; in this position, therefore, the external pressure of the air will diminish the weight of the gasometer 358 lbs., and this must be taken into calculation in regulating the chain. The tendency to rise in the gasometer increases as it fills, or rises, but at the same time its loss of weight by submersion in water diminishes. Further, the tendency of the cylinder to rise increases with its capacity and dimensions,—the loss of weight, on the contrary, with its amount of surface,—therefore, in diminished proportion; so that, with a certain diameter, these two compensate each other, or the pressure may even diminish as the cylinder sinks.

Gas-holders are now made so light that they frequently require

loading, to force the gas out, instead of counterpoises. They are often not suspended, but guided by a number of rods round the circumference, which extend their entire height.

When gas was first introduced into the metropolis, a recommendation was made to Government by a Commission of the Royal Society, that no company should be allowed to construct gas-holders exceeding 6,000 cubic feet capacity, which were to be confined in very strong buildings. The holders now constructed frequently contain between 400,000 and 500,000 cubic feet, and there is one in Philadelphia 140 feet diameter and 70 feet high, capable of containing more than a million cubic feet.

Governors and Regulators.—Whoever has had occasion to use gaslight knows from experience that the size and brilliancy of the flame, after having been once brought to the right pitch, do not remain the same, but require from time to time to be brought back to the original state by altering the cock; this is chiefly the case in the late hours of the evening. The changes in the flame are true indications of an alteration in the pressure, which is exerted as far back as the gasometer; yet the latter cannot be the cause of these irregularities, being capable of the most perfect control. Independent of some secondary causes, the want of uniformity in the size of the flame is mainly due to the different times at which the burners, in connection with the same pipe, are closed. Suppose a pipe to supply one thousand burners of equal size, and the flame from one of these to have been regulated in the beginning to its highest pitch, without smoking; then, at ten o'clock in the evening, when two hundred householders have put out their lights, one-fourth more gas will issue from the burner in the same time, and the cock will have to be closed in proportion, in order to produce the same-sized flame. Inventions for preventing this irregularity are called *governors* or *regulators*, and their object being to render the action of the burner perfectly independent of any alteration in the pressure, it has been an object in constructing them to make the changes of pressure themselves work a mechanical arrangement, enlarging or lessening the aperture of supply in such a manner that an equal quantity of gas shall always pass out.

The construction of the governor as manufactured by Mr. Wright, Westminster, is shown in Figs. 375, 376, and 377. It consists of a miniature gas-holder G, suspended by a cross-arm B, with a counterpoise, over the inlet-pipe leading from the large gas-holder to the principal main. To the interior of the

bell-shaped vessel G, which is capable of rising and falling with the pressure within, in the water-groove T, a conical valve C is attached, fitting exactly, when at its full height, into the aperture

FIG. 375.

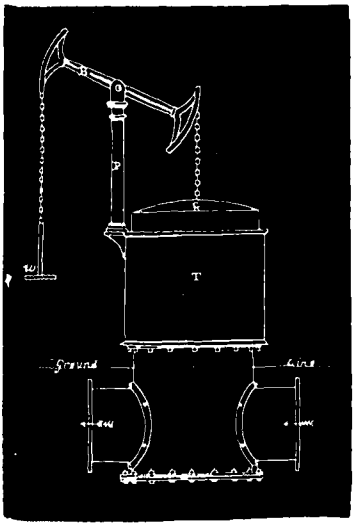
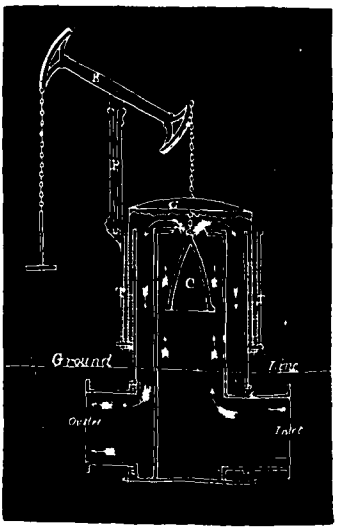
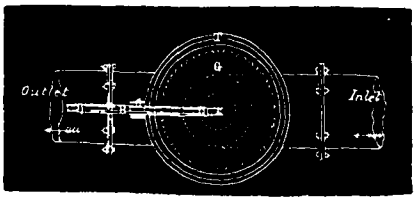


FIG. 376.



of the inlet-pipe, which delivers gas from the large holder, and diminishing the size of the orifice according to the height of the small holder G. When the pressure of the gas is weak, the cone

FIG. 377.



descends with the holder, the aperture is enlarged, and a large escape of gas occurs; on the contrary, when the pressure increases, the cone rises, the orifice is lessened, and a smaller proportion escapes.

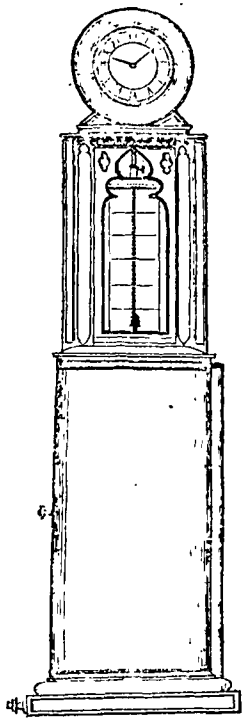
Self-registering pressure-indicators are employed to indicate to the manufacturer the pressure at which the gas is sent into the mains at all times of the day and night. They are of two kinds, the indications being registered in the one on a sheet of paper

revolving on a vertical axis, and on the other upon a horizontal axis.

Both are constructed of two small cylinders, the inner cylinder being inverted in the water of the outer, upon the principle of the gas-holder, and rising and falling with the pressure of the gas conducted into it by a small pipe from the main. A pencil is attached to the top of the movable cylinder, and bears in the one upon a small cylinder rotated once in twenty-four hours by clock-work, and covered with a sheet of paper ruled to correspond with the hours of the day. If the pressure be constant, a straight line will be formed upon the paper; if irregular, the line will be more or less curved. This arrangement is shown in Fig. 378.

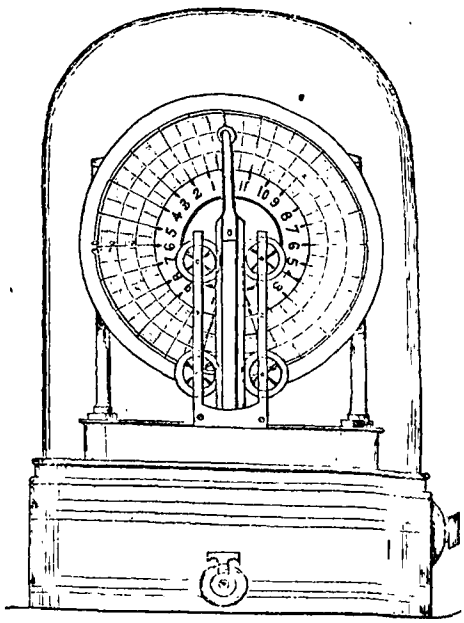
The pressure-indicator, Fig. 379, has a circular disc, rotated

FIG. 378.



Crosley's Indicator.

FIG. 379.



Wright's Indicator.

once in twenty-four hours on a horizontal axis moved by clock-work. A is the outer cylinder, or tank, which is entirely closed

in, excepting a few holes in the bottom, to allow the water in A to communicate with the water in C; B is the inlet-pipe for the gas; C is an inner cylinder open at the top; D a rod, carrying the pencil at the upper extremity, and attached at the lower to a float resting on the water in C. As the water rises and falls with the varying pressure of the gas between the two cylinders, the motion is communicated to the pencil, and noted on the disc of paper. These instruments admit of the pressure being regulated according to the requirements of consumers at different periods during the twenty-four hours.

Gas-pipes or Mains.—The distribution of the gas from the gasometer is effected, as far as the principal mains are concerned, by means of cast-iron pipes; the smaller pipes, for the supply of houses, are composed of drawn leaden tubes. Copper pipes are dangerous, on account of the production of a peculiar pulverulent deposit, formed by the combination of the metal with some of the ingredients of the gas, which takes fire spontaneously in the air.

In flowing through the pipes, the gas is subjected to friction against their sides, which increases rapidly as their diameter diminishes. As it is very inconvenient to overcome, by a greater pressure in the gasometer, the diminution of velocity caused by friction in the current of gas, it becomes necessary to widen the pipes to such an extent that the velocity in the current of gas at different distances from the gasometer may not sensibly vary, and it is therefore of importance to be able to calculate the effects of friction. Assuming a constant pressure to exist in the gasometer, the resistance caused by friction will stand in some relation to the root of the length of the pipe (l). The quantity of gas q which flows out depends, therefore, first upon that relation (upon $\sqrt{l}$), and also upon the width, *i. e.* upon the square of the diameter (d^2), increasing with the latter, and diminishing with the former. According to Prechtl, $q=\frac{d^2}{\sqrt{l}}$, and a tube 316 feet in length allows 400 cubic feet of gas to pass in an hour, when its diameter is one-tenth of a foot. We obtain, therefore,

$$q : \frac{d^2}{\sqrt{l}} = 400 : \frac{0.1^2}{\sqrt{316}}, \text{ whence } d = \sqrt{\frac{q\sqrt{l}}{711000}}.$$

The relations between the dimensions of the pipe, the pressure of the gas, and the velocity diminished by the effect of friction, &c., have been made the subject of repeated experiment by engineers,

and the practical mathematical formula which is most conformable to the experimental result is, according to Pole*—

$$Q = 1350\ d^2 \sqrt{\frac{h\,d}{s\,(l+d)}}$$

In which

Q = Quantity of gas passing per hour in cubic feet.

l = Length of pipe in yards.

d = Diameter of pipe in inches.

h = Pressure in inches of water.

s = Specific gravity of gas, that of atmospheric air being 1.

The results of numerous experiments since made upon coal-gas appear to give on an average about 15 per cent less discharge than is indicated by the formula. This would require an alteration in the constant from 1350 to 1150. But as the experiments were made only on one pipe, it would be desirable that more experiments upon pipes of variable dimensions should be made before altering the formula.

The above equation may be translated in the following manner :—

1. Multiply the pressure by the diameter of the pipe, both in inches.
2. To the length of the main in yards add the diameter in inches, and multiply the sum by the specific gravity of the gas. Divide the product by the result of (1), and extract the square root of the quotient.
3. Multiply the square of the diameter of the pipe in inches by the constant coefficient 1350, and divide by the result of (2). The quotient will be the quantity discharged in cubic feet per hour.

All causes which tend to produce eddies or disturbance of the particles of fluid amongst each other must inevitably check the velocity and diminish the discharge: for this reason sharp bends, contractions, and enlargements, must be avoided as much as possible.

The cast-iron pipes are generally about 9 or 10 feet long, and are furnished with a shoulder at the one end, and a mouth-piece at the other. Fig. 380 shows the manner in which the shoulder of the one pipe is placed into the mouth-piece of the other when they are laid down. The space between the two is filled with greased tow, which is rammed in, and lead is then melted round the whole,

* "Journal of Gas-lighting," June 1852.

which renders the joint perfectly air-tight. It is still more easy to form a tight joint with the smaller pipes, the leaden tube being flexible and easily soldered. The proper distribution of the gas, as well as the function of the gasometer, render it necessary that there should be stops in different parts of the mains; stop-cocks answer well enough for the smaller pipes, but are not suited to the principal mains, where they would necessarily be very awkward and excessively large. The more convenient water-valve, Fig. 381, has been substituted, and by its means a perfect stop is effected without any cock. The two separate pipe-ends *a* and *b* enter the vessel *c c*, which is filled with water, and above which a tin cylinder *d d* is suspended, dipping below the level of the water *n*, and attached to a counterpoise *p*. In the position shown in the drawing, the tubes are in connection, but can be disconnected at once by the removal of the weight *p'*, which causes the cylinder to sink, and the partition *e* to become immersed. Leakage in the pipes, which often occurs at bends and corners, is attended not only with loss but danger, for illuminating gas explodes when mixed with air in certain proportions. The fact that such explosions are uncommon, and seldom occur in inhabited rooms, is easy of explanation. The gas, on entering a room, gives warning of its presence by its smell, and becoming mixed with much more air than that proportion with which alone it is explosive, little danger is incurred; in the crevices of walls and ceilings, the probability of an explosive mixture being generated is much greater, and it is generally when gas has accumulated in such parts that the introduction of a light explodes the mixture.

FIG. 380.

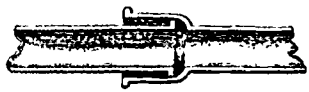
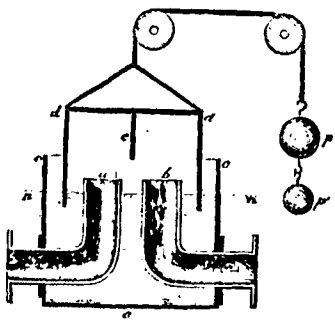


FIG. 381.



Gas-meter.—As a check upon the gas-works themselves, and as a means of calculating between the works and the larger consumers, when the gas cannot be paid for by the number of burners or hours of consumption, a safe and easy method of ascertaining the quantity of gas consumed becomes necessary, which the ingenuity of English mechanicians has effected by the *gas-clock* or *gas-meter*.

Clegg was the inventor of the first self-acting machine for the measurement of gas. The instrument first contrived accomplished its object in an imperfect manner. Valves and a stuffing-box formed part of the mechanism, which, by increasing the friction, interfered much with the regularity of the measurement. John Malam improved considerably upon Clegg's invention, and introduced the principle of the Archimedian screw into it. This form of meter, called the wet-meter, is still most extensively used. The chief improvement consisted in making all the valves hydraulic, and dispensing with the stuffing-box, in which the axis supporting the measuring chambers worked. In Malam's meter a quantity of water equal to the volume of gas measured was successively carried through the chambers of the wheel; this impeded its action. Crosley and Wright, by altering the position of the slits and apertures, as well as the form of the partitions in the revolving drum, have brought the wet-meter to its present state of great perfection. Fig. 382 shows a section of this instrument, and Fig. 383 a section in perspective at right angles: Fig. 384 is a

FIG. 382.

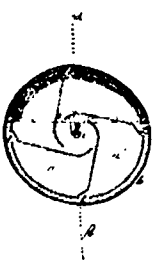


FIG. 383.

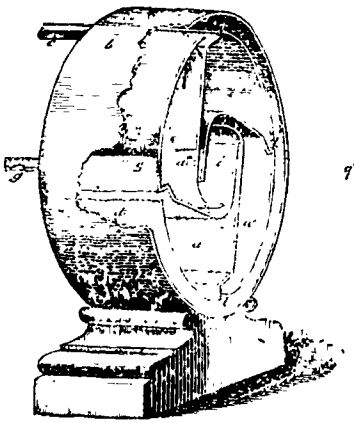
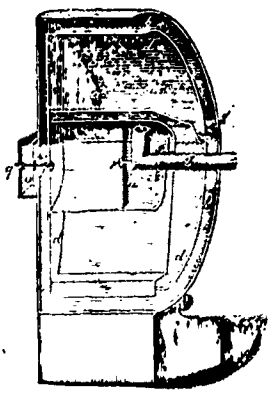


FIG. 384.



similar section parallel to the axis in the direction of the line $\alpha\beta$ in Fig. 382. The principle is the following:—When a number of vessels of a certain capacity—for example, 1 cubic foot—are so arranged that (without loss of gas in the interval) one after the other shall be filled by the gas in passing, and for this purpose are inverted in water into which the gas enters, just as was the case on a large scale with the gasometer, it follows that just as many

cubic feet of gas will have passed, as there are vessels that have been filled. If these vessels (for instance, 4) are attached to a common axis, upon which they revolve as they fill and rise, every revolution of the axis will correspond with 4 cubic feet of gas that have passed. In the gas-meter itself, instead of separate vessels each containing 1 cubic foot, compartments of a drum of equal and known capacities are employed. In a case *b b*, more than half-filled with water, this drum *d d* revolves, and is divided by four curved partitions into as many chambers, *a*, *a'*, *a''*, and *a'''*. The contents of each chamber are enclosed at the front and back by the straight sides of the drum *d*, above by the crooked partition, and below by the water *s s*. Towards the middle, the partitions are bent round to form the space *i*, and slits are thus left for the passage of the gas from one chamber to the next: similar slits *t t* are made at the periphery of the drum for the exit of the gas. The tube *g* for the admission of the gas passing through the back of *b*, enters *d* by an aperture (under water), and extends a few inches into *i*; it is there turned upwards, with its mouth above the level of the water (into the chamber directly over it, in this case *a'*). At the bend in *g*, one of the pivots *r* of the drum *d* is fixed, which works in the rod *u*. The latter *u* is fixed in two points at *i* (therefore on *d* itself). The peg *q* on the back side of *d* is the other pivot; it passes through an aperture in *b*, and supports the toothed wheel *o*. The chamber *a*, or *a'*, &c., in being filled with the gas, becomes lighter and rises, causing *d* to revolve, until it rises above the level of the water *s s*; it then parts with its contents through the slit *t*, to the space between *b* and *d*, from whence the gas is carried forward through the tube *c*. It is obvious that at the same moment (in which the gas is evolved) the next chamber becomes closed above *g* to receive the next portion of gas, and so on. The toothed wheel *o* gives motion, by means of clockwork, to hands on the dial-face in front of *d*, so that each division indicated on the plate represents either 1, 10, or 100 revolutions, and thus the quantity of gas which has passed is ascertained in cubic feet. In determining the amount of gas by means of the meter, the temperature ought to be taken into consideration, for 1000 cubic feet at 0° C. (32° F.) will become 1075 cubic feet at 20° (68° F.)

Crosley's wheel is so formed that the gas alone is screwed through the chambers by the pressure exerted by the gasometer, while the water passes directly from one chamber to the other, and forms much less impediment to the rotation of the wheel. Wright's

improvement upon Crosley consists in cutting off from the outlet and inlet hoods of the wheel a piece of superfluous metal, which has the effect of diminishing the friction and enabling wheels of larger diameter and less depth to be employed.

FIG. 385.

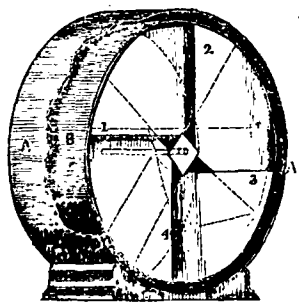
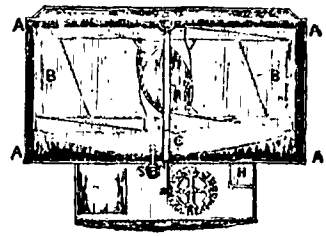


FIG. 386.



Figs. 385, 386, and 387 show different sections of Wright's meter.

The Figs. 388 and 389 show the form of meter patented by Edge.

FIG. 387.

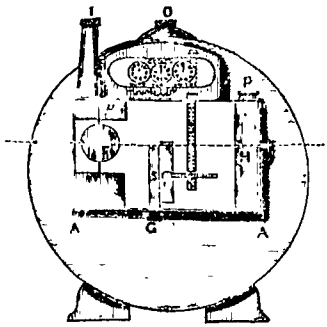


FIG. 388.

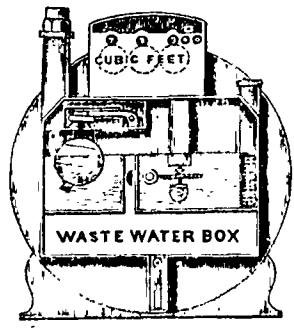


FIG. 389.

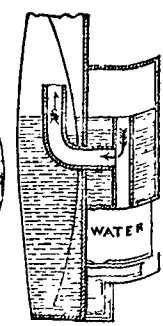


Fig. 388 is a front view, the front plate being removed, and some parts being shown in section: Fig. 389 is a transverse section. The peculiarities of this instrument consist in the float which is seen connected with a valve where the gas enters the meter, the object of which is to prevent the entrance of gas when the water in the meter falls below a certain level. The float then sinks with the water, closes the valve, and cuts off the supply of gas. The pipe supplying the gas is also cut off at the proper water-level, so that if there should at any time be too large a quantity of water in

the meter, it will at once flow over into a waste water-box placed below for receiving it. The uniform level of water is thus secured, and the registration rendered very correct.

The ordinary wet gas-meter is unexceptionable where fraudulent means are not employed for under-estimating the amount of gas consumed, but its construction admits of great deceptions being practised by dishonest consumers. If, for instance, the water-level in the meter be lowered, more gas will pass through than is registered by the instrument; if the case of the meter be tilted forward to an angle of from 5° to 13°, according to its construction, and a proportion of the water drawn off, so as to expose the outlet of the measuring chamber, the gas will pass through it without affecting the index, and without being registered at all. This is constantly done, and the large amount of gas which is unaccounted for in the records kept at gas-works, and which is frequently attributed to leakage, is no doubt traceable to this nefarious practice. In cold weather the water in the meter is liable to freeze, and the passage of the gas is then completely stopped. Mr. Lowe has proposed the use of a solution of caustic potash or soda, which is not so easily affected by frost, to replace the water in the meter, which will also tend to render the gas more pure, should either carbonic acid or sulphuretted hydrogen have escaped the general purifiers. The grave objections to the use of the wet meter, stated above, have given rise to great ingenuity in the construction of a variety of measuring instruments, in which the use of water or any liquid is dispensed with.

Clegg has, again, displayed remarkable ingenuity in the construction of the dry gas-meter which bears his name, and which is shown in Figs. 390 and 391, and thus described by the inventor:—

"In a small cylindrical vessel two glass cylinders, connected together by a bent tube *b*, exhausted of air, and half filled with alcohol, are made to vibrate on centres *e* and *e*, and are balanced by a weight *f*. An excess of heat applied to either cylinder causes the liquid to flow into the other, upon the principle of Leslie's differential thermometer. C is a hollow brass box, called the heater, projecting about one inch above the cylindrical meter. At *a* issues a small jet of gas, which, when inflamed, gives motion to the cylinders.

"The gas enters the meter by the pipe A, and circulates throughout the double case B; having passed round the case B, a portion of it enters the top of the box C by the pipe D, and passes out

again at the bottom by the tube c into the meter; the rest of the gas enters the body of the meter through holes in the curved faces of the hoods E E, and, after blowing on the glass cylinders, passes to the burners by the outlet pipe.

"To put the meter in action, let the jet *a* be lighted about an hour before the burners are wanted. In most cases this jet will

FIG. 390.

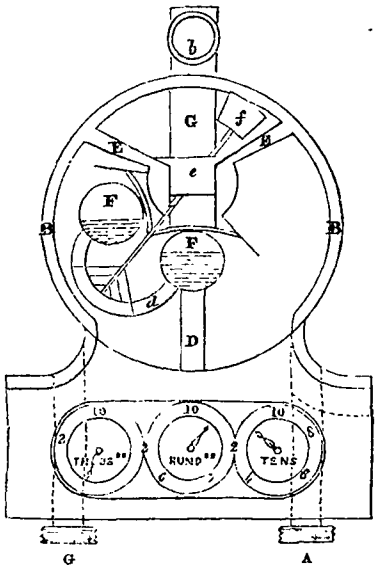
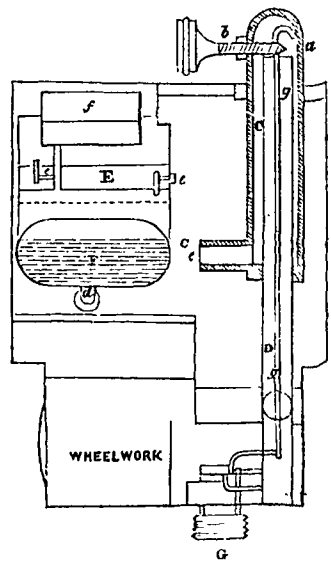


FIG. 391.



be lighted all day as a useful flame. The hole *a* is so situated on the box c, that, whatever be the size of the jet, a fixed temperature is given to the box, that temperature depending on the quantity of flame in contact with the box, and not on the length of the jet. The jet being lighted, and the box c heated, the gas which passes through it is raised to the same temperature, and, flowing out at the tube c, impinges on the glass cylinder which happens for the time to be the lowest; the heated gas soon raises a vapour in the lower cylinder, the expansion of which drives the liquid into the upper one, until it becomes heavier than the counterpoise *f*. When the cylinders swing on their centre, the higher one descends and comes in the line of the current of hot gas, and the lower one ascends; the same motion continues as long as the jet *a* burns. The same effect on the cylinders is maintained, however the outward temperature may change by the cold gas, which,

issuing from the curved side of the hood E E, impinges on the upper cylinder, and hastens the condensation of the vapour which it contains.

"The cold gas and the heater vary in temperature with the room, and thus counteract each other.

"The lighting of the jet *a* is essential to the action of the meter: in order to ensure this, the supply of gas to the burners is made to depend on it in the following manner:—The pipe G, by which the gas leaves the meter, is covered by a slide-valve, which is opened and shut by the action of the pyrometer *g*; the pyrometer is in communication with and receives heat from the jet, and opens the valve when hot, closing it again when cold.

"The speed at which the cylinders vibrate is an index of the quantity of heat communicated to them, and is in exact proportion to the quantity of gas blowing on them through the pipe C and curved side of the hoods E E.

"The gas passed through the heater is a fixed proportion of the whole gas passing the meter; therefore the number of vibrations of the cylinders is in proportion to the gas consumed.

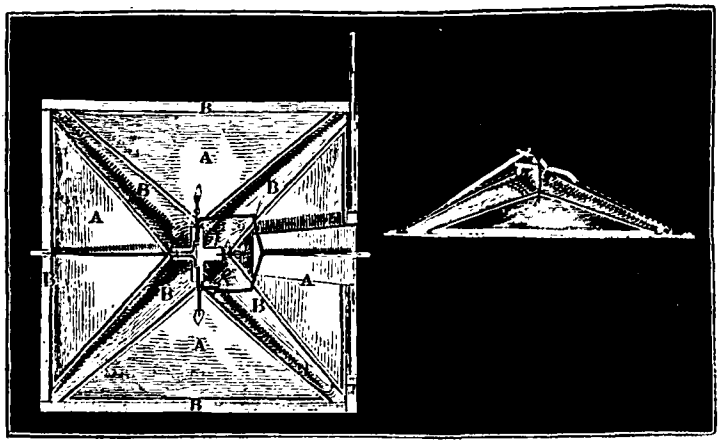
"A train of wheel-work, with dials, similar to that used in the common meter, registers the vibrations.

"Simplicity, accuracy, and compactness are the most remarkable features of this instrument, and the absence of all corrosive agents will ensure its durability."

Other contrivances have been introduced, in which the gas is measured by the number of times that a certain volume will fill a chamber capable of undergoing contraction and expansion by the passage of the gas. These alternate contractions and expansions of the chamber set certain valves and simply-constructed arms in motion, which, by the aid of a few wheels, can be made to turn the hand of a dial, as in the ordinary wet meter. Two of the most recent inventions, which appear well calculated for affording accurate measurements, are the meters of Defries and of Messrs. Croll and Richards.

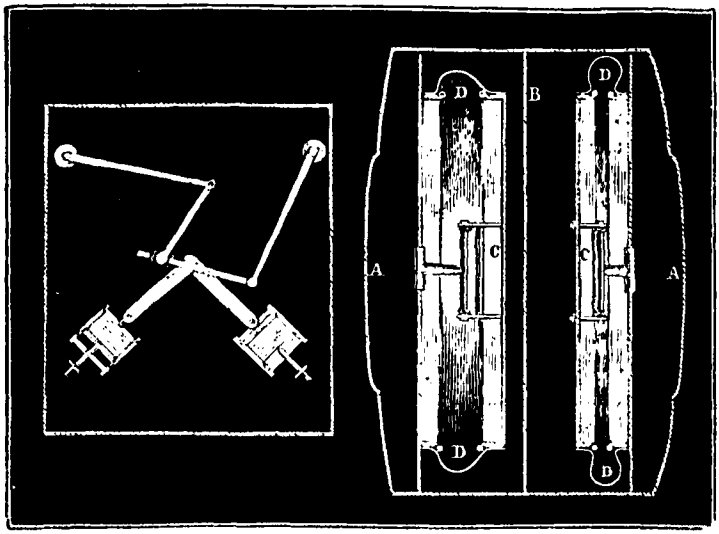
Defries' meter consists of three measuring chambers, separated from each other by flexible partitions of leather, partially protected from the chemical action of the gas by metal plates. The metallic protection is shown at *AAA* in Fig. 392, and the flexible leather at *BBBB*. The pressure of the gas expands the flexible partition, which then assumes the form of a cone, as represented by the small side cut, Fig. 392; the motion of this flexible cone backwards and

FIG. 392.



forwards on both sides of its base sets the machinery in action, and measures the amount of gas which passes through the meter. The object in introducing three chambers into the meter is, that its

FIG. 393.

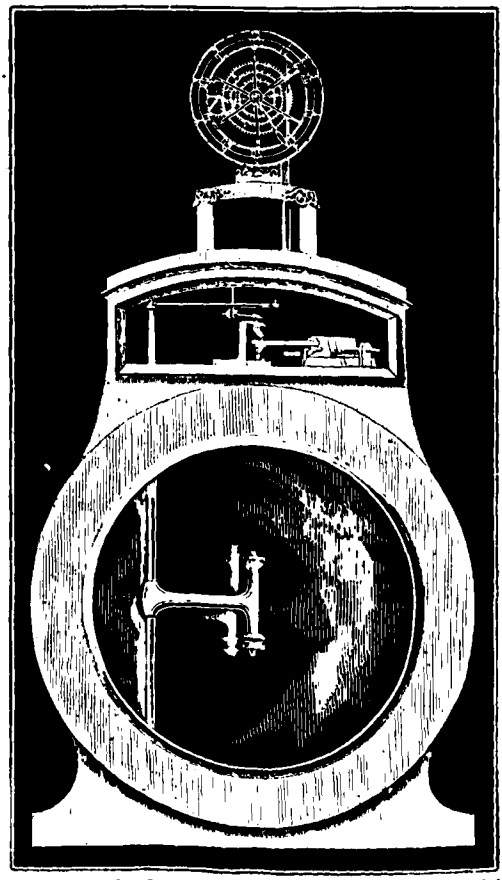


action may be continuous, like that of a three-throw pump, and to prevent that oscillation of the lights which sometimes results from the use of two chambers.

Messrs. Croll and Richards' meter claims superiority over that

just described, in being independent of the flexible leather hinge, so that any contraction or expansion it undergoes cannot alter the registration of the gas. The meter consists of a cylinder or case *A A*, Fig. 393, divided by a plate *B* in the centre into two separate cylindrical compartments, which are closed at the opposite ends by metal discs *C C*. These metal discs serve the purpose of pistons, and are kept in their places by a kind of

FIG. 394.



universal joint attached to each; the space through which the discs move by the action of the gas, which affords the means of measurement in this meter, is governed by metal arms and rods, shown in the side cut, Fig. 393, which space, when once adjusted, cannot

vary. To avoid the friction attending a piston working in a cylinder, a band of leather *DD* is attached, which acts as a hinge, and folds with the motion of the disc; this band is not instrumental in measuring the gas, so that its contraction or expansion would only decrease or increase the capacity of the hinge, the disc being still at liberty to move through the required space. The leather is also attached in such a manner that it can only bend in one direction, and this renders it much more durable.

The machine is quite comparable to a steam-engine measuring its steam, which it does in all cases by the strokes of the piston. The gas enters the cylinder at the top, from the space occupied by the arms, valves, &c., Fig. 394, and forces the discs bodily forward through a certain space; the motion communicated by the discs to the arms and rods causes the supply of gas to be cut off, and allows it to escape by another valve; at the same moment the gas is admitted to the other side of the disc, and this is forced to return to its original position, traversing, of course, the same space as before. Each backward and forward motion consequently indicates the passage of a constant quantity of gas, and the same apparatus which admits and shuts off the supply by means of valves is connected with clockwork, and thus the motion of the disc, or the quantity of gas which has passed through the meter, can be indicated upon a dial-plate, as in the ordinary wet meter.

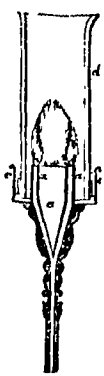
The Burners.—From the leaden pipes—in the circuit of which the meter is placed, if used at all—the gas passes to the *burners*, each of which is furnished with a separate brass stop-cock. Good tight stop-cocks are much more difficult to make for so light a fluid as gas, than for liquids. The burners are very similar to lamp-burners; but as neither wick nor oil-level require special consideration, the management of the gas-burners is comparatively simple. The amount of gas consumed in a given time, however, must bear a proper relation to the supply of air, that the flame may not smoke or burn with a blue flame. This is regulated partly by the cock attached to the burner, and an excess of gas is avoided by making the apertures of the burners very small, which increases the velocity of the current. The same quantity of gas issuing from a wide opening would produce a thick, short, and dull flame, because the surface in contact with the air would thus be increased. No gas-flame should be allowed to issue from a wide opening, for the same reasons that thick massive lamp-wicks are not desirable.

When the burner has a single aperture of the diameter of a bristle,

a *simple jet* is produced in the form of a long, thin, conical flame. The *bat's-wing*, or flattened flame, which the gas forms when it issues from a narrow slit, instead of a round aperture, is much more appropriate, and combines all the advantages of the flat wicks before mentioned. A similar and equally good flame is produced by a burner with two apertures close to each other, the channels of which are inclined inwards, so that both the currents of gas cross each other at their base. They then form a flat flame spreading out in the form of an inverted triangle, and the burner is called a *fish-* or *swallow-tail.* These forms of burners are shown in Fig. 5, Plate III.

Simple flames of this kind are generally burnt without any chimney. When a greater quantity of light is required, or greater intensity of flame, the Argand burner, Fig. 395, is generally chosen.

FIG. 395.



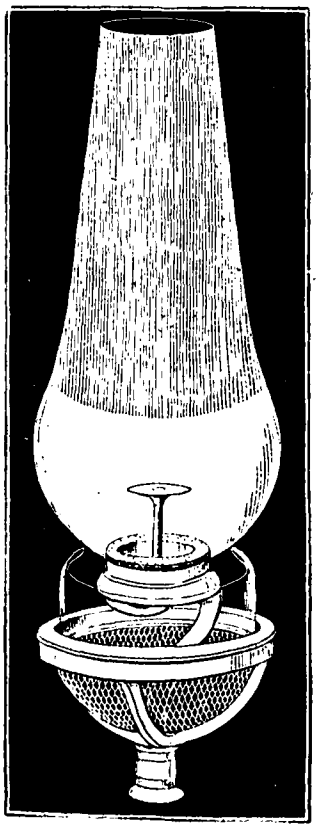
The gas from the pipe enters the annular space *a a*, which is closed above by the flat plate *b*, Fig. 396. In this plate are a number of fine apertures, arranged in a circle, and so near to each other that the separate flames unite to form one hollow cone. The gallery *c* supports the chimney *d*; and to produce an internal current of air, *e* is open at the sides. The distance between the apertures in these burners varies with the quality of the gas, as does the size of the aperture itself. An aperture $\frac{1}{32}$ of an inch is often used for coal-gas, and one of $\frac{1}{50}$ of an inch for oil-gas; for the former they should be $\frac{1}{8}$ of an inch, for the latter $\frac{1}{6}$ of an inch apart. These dimensions are, therefore, larger for coal-gas than for oil-gas, the latter possessing double the illuminating power of the former. The holes should be as uniformly and accurately bored as possible; if this is not done, there will be parts of the flame which will smoke. Sometimes the heat of the flame is applied to warm the current of gas before it issues from the burner, by which means the flame is less cooled, and whiter light is produced. For this purpose the gas-pipe is formed into several revolutions at a certain height above the flame.

FIG. 396.

An important improvement upon Argand's burner for illuminating public places, bridges, &c., where one large lamp and a very intense light is preferred to a number of small ones, is the *bude burner*, proposed by Gurney, upon the principle of

Fresnel's lamp. Two, three, or more hollow ring tubes, each furnished at the top with a circle of holes, form the principal part of the burner, and are connected at bottom with parts of the gas-pipe bent horizontally, from which they receive the gas. Each inner ring is placed somewhat higher than the one before it, so that a number of concentric flames are produced, the light of which is thrown by reflectors in the proper direction. The bude burner must not be confounded with the *bude light* of the same inventor, which is produced by conveying oxygen into the inner space of an Argand's oil lamp. A similar effect to that of the bude burner is produced by a number of single flat flames arranged in a ring. The Victoria Bridge, at Manchester, for instance, is lighted by such a burner, consisting of two concentric rings, each containing 12, therefore altogether 24 flat flames; the inner ring, 4 inches in diameter, stands 1 inch higher than the outer, which is 6½ inches in diameter, the whole thus being rounded off in the shape of a rose.

FIG. 397.



A great variety of gas-burners have been successively brought into public notice, all of which lay claim to the production of an increased intensity of light with a smaller consumption of gas. It is impossible, however, from a mere inspection of the flame produced by these burners, without accurately measuring the amount of gas consumed by each, to arrive at any conclusion as to which form is the most economical or generally desirable. Until impartial comparative experiments have been instituted with all, decided preference cannot be ascribed to any one in particular.

Fig. 397 is a representation of Whinfield's lucent burner in which the Liverpool button is applied to an Argand gas-burner, and the peculiar form of chimney causes an external

current of air to impinge at a certain angle upon the flame, producing the same effect as the metallic cone in the solar lamp before described: a basket of wire gauze is fitted into the crutch of the burner, which moderates the supply of air from below, and prevents the flickering caused by sudden draughts. By fixing the chimney to a circular ring, which screws up or down upon the triangular support, Mr. Lowe is enabled, in his improvement upon this form of burner, to alter the direction of the external current caused by the contraction of the chimney; and by converting the button into a screw, its height can also be altered, and the internal current regulated.

Fig. 398 shows a form of burner, patented by Mr. Leslie, in which the gas is caused to flow through a number of small copper tubes, instead of from the apertures of an Argand burner. The object of this is to effect a more complete combustion of the gas by surrounding each single jet with abundance of air, as it issues from the orifice. A low form of chimney or combustion-chamber is adapted to this burner, which diminishes the velocity of the draught. This burner was alluded to, on a former occasion, as an instrument for testing the purity of gas. If the gas is impure, the orifices of the copper tubes become stopped up either with sulphuret of copper or the ammoniacal oxide, and require to be cleansed with a stiff brush. The only effectual remedy for this objection to the burner is the use of purer gas, and this must be obtained, when not supplied in a pure state from the gas-works, by the use of a separate purifier in each house.

Ventilation of Gas-burners.—Serious objections stood in the way of the introduction of gas-light into private dwellings, when the system was first introduced, in consequence of the impurities contained in the gas, the great heat to which the temperature of the rooms was raised, and the large quantity of carbonic acid evolved. Although, for an equal amount of light, the carbonic acid produced from gas is not so great as with common candles or oil-lamps, yet more light was always expected of gas, and consequently more carbonic acid produced. For every cubic foot of gas burnt, rather more than a cubic foot of carbonic acid is produced. A pound of London coal-gas contains, on an average, 0.3 of hydrogen and 0.7 of carbon; it produces, when burnt, 2.7 of water and 2.56 of carbonic acid gas; and consumes 4.26 cubic feet of oxygen, which is the quantity contained in 19.3 cubic feet of air. It is thus obvious that the air of a close chamber must soon be vitiated by the combustion of gas, and that the consequences of breathing an

atmosphere impregnated with a large proportion of carbonic acid, must soon be felt by the consumer. The water evolved at the same time, in the state of steam, was found to be seldom free from compounds of sulphur, which, condensing upon furniture, books, goods in shops, &c., damaged them to a considerable extent. Serious injury was sustained by the library of the Athenæum Club from this cause, and the large quantity of water evolved from the Bude-burner in light-houses, condensing on the glass

FIG. 398.

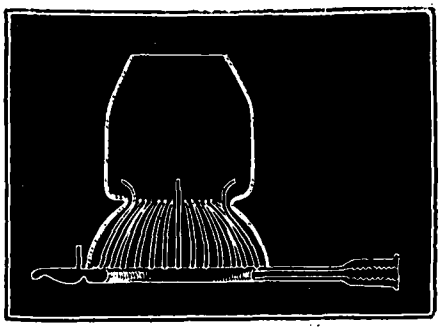
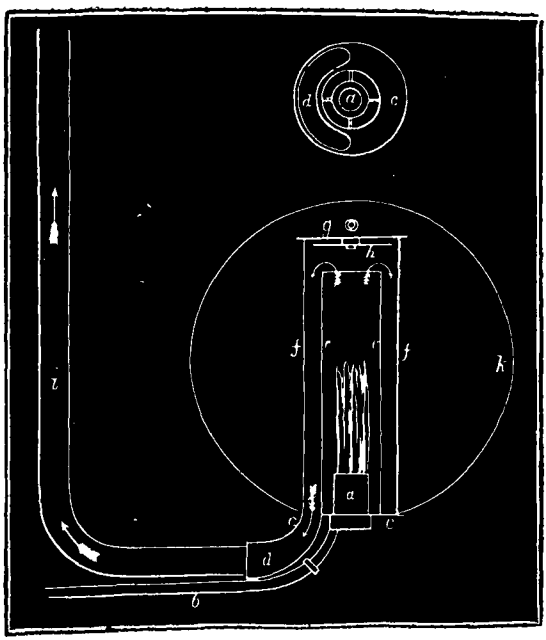


FIG. 399.

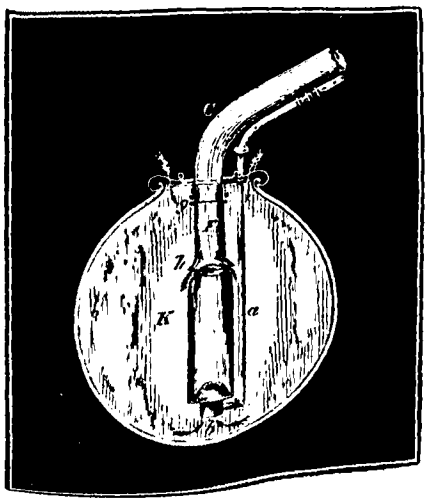


windows and impeding the passage of the light, attracted the attention of Mr. Faraday to the invention of some means for effectually removing the noxious products of combustion. After

several more or less successful trials, the method illustrated by Fig. 399 was adopted, which exhibits a beautiful adaptation of the principle of a descending draught to a lamp-burner. An ordinary Argand burner, *a*, with a common straight chimney *e e*, is employed; the glass holder *c* is, however, so constructed as to sustain not merely the chimney, but an outer cylinder of glass also, *f f*, larger and taller than the inner one *e e*; the glass holder has an aperture *d*, connected by a mouth-piece with a metal tube *i*, which serves as a ventilating flue, and which, after passing horizontally to the centre of the chandelier, ascends to produce draught, and carry off the products of combustion into the chimney or the open air; *d* is the pipe connected with the burner for supplying gas. The outer cylinder *f* is closed at the top by a plate of mica, *g*; or still better, by two plates of mica, one resting on the top of the glass, and the other *h* dropping a short way into it. They are connected together by a metal screw and nut, which also keeps them a little apart. The chimney and burner may then be surrounded by a ground-glass globe, which has no opening, except at the bottom, for the admission of air to the burner. The course of the current of air, carrying with it the products of combustion, is indicated by the direction of the arrows.

The intense heat produced by the hot current of air traversing the space between the two glass cylinders, causes the glass to become more or less opaque, and thus obstruct the passage of the light. To avoid this, and at the same time the unsightliness of a descending tube, which must of course throw a shadow, Mr. Rutter has applied the same principle, in a still more elegant and perfect manner, to his ventilating gas-burner, a section of which is represented in Fig. 400. The burner is shown at *b*, with an ordinary chimney, discharging the products of combustion into the metal tube *F*; *K* is a large glass globe, open at the top, in the vicinity of the

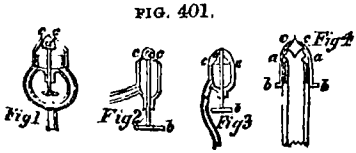
FIG. 400.



metal flue *F*, from which it is suspended. The air for feeding the flame descends in the direction of the arrows, enters the burner at *b*, and is carried off through the flue *FC*, after having supplied oxygen to the flame and become vitiated. Ventilating burners of this kind not only prevent the diffusion of the products of combustion through the apartments in which they are erected, but with the hot current of gas ascending through the metal tube, a large quantity of air from the room is also carried away, and a beneficial ventilation established. Some slight difficulties occurred on the first introduction of these ventilating arrangements, which now appear to have been successfully overcome. One of these arose from the large quantity of water which collected in the more distant and cooler part of the ventilating flue, and flowing back upon the burner extinguished the light. By inclining the tube, and carrying it into the chimney of the room, this may be avoided, particularly when a fire is burning at the same time under the chimney. Another difficulty was raised by the insurance companies, who objected to a hot tube, or flue, being carried nearer than within a certain distance of the beams in the ceiling of the room, which precluded, in many cases, the flue from entering the chimney, as the beams supporting the floors frequently lie in a direction at right angles to the course of the chimney, and the flue was consequently obliged to be carried parallel with the beams into the open air; in this case the burner is frequently subjected to a draught in an opposite direction from without, and the steadiness of the flame is very much impaired. When the flue is constructed of a double casing of metal enclosing a stratum of air, or when porcelain or stoneware tubes are used, there appears no good reason for apprehending danger from this source, while the advantages gained, both in health and comfort, as well as the lesser injury sustained by furniture, &c., by the use of ventilating burners, will, it is to be hoped, render them very general.

The burners shown in Figs. 401 and 402 are those proposed by Mansfield for burning mixtures of air or other incombustible gases with hydrocarbons of different degrees of volatility, but are also applicable to any gaseous combustible. They are all constructed with a view of producing a film of flame by allowing the gas to pass through a slit, the size of which is capable of regu-

FIG. 401.

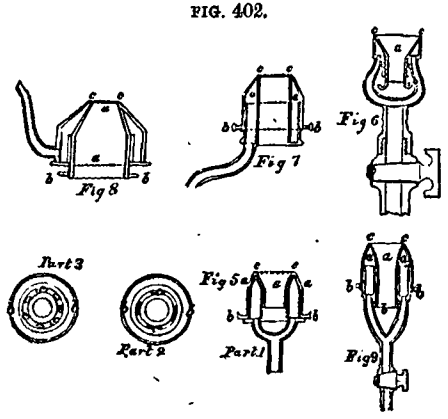


lation. The more hydrocarbon a mixture contains the narrower should be the slit through which it escapes from the burner.

In the Figs. 1, 2, 3, and 4 of Fig. 401, no air is admitted to the centre of the flame, and the size of the orifice *c c* is regulated by the moveable part *a*, which in the first three is a button moved by the thumb-piece *b*, and in Fig. 4 a cap forming the outer part of the burner.

In the burners shown in Figs. 5, 6, 7, 8, and 9 of Fig. 402, air is admitted to the centre of the flame, and in Fig. 5 the moveable part is a cap consisting of two concentric cylinders or cones, which are joined at their upper edge, and perforated with a certain number of slits or holes of various forms; these apertures correspond to similar apertures in the fixed part of the burner below, upon which the cap fits tightly. By turning the cap round, the quantity of gas which escapes is regulated. The horizontal sections, Parts 2 and 3, are plans of different caps with different forms and numbers of perforations.

FIG. 402.



In Figs. 6 and 8 the inner cylinder or conical wall of the burner is moveable; in Fig. 6 by means of a screw, in Fig. 8 by simple sliding contact of the curved surfaces.

In Fig. 7 the outer cylinder is moveable, and in Fig. 9 both the inner and outer.

Before closing the mechanical descriptions connected with the manufacture and supply of gas, we append in Fig. 403 the plan of a large gas-work drawn by Mr. Hedley for Dr. Ure's Dictionary. It is calculated for the arrangement of 400 retorts, 12 wet lime-purifiers, and 2 washers; 12 large double or telescopic gas-holders, capable of storing 1,000,000 cubic feet of gas; and coal stores capable of holding 10,000 tons of coal. A is the retort-house, 300 feet long, 56 feet wide; B are the retort beds; C the chimney stack; D flues; E hydraulic mains; F coal stores, each 300 feet long, 30

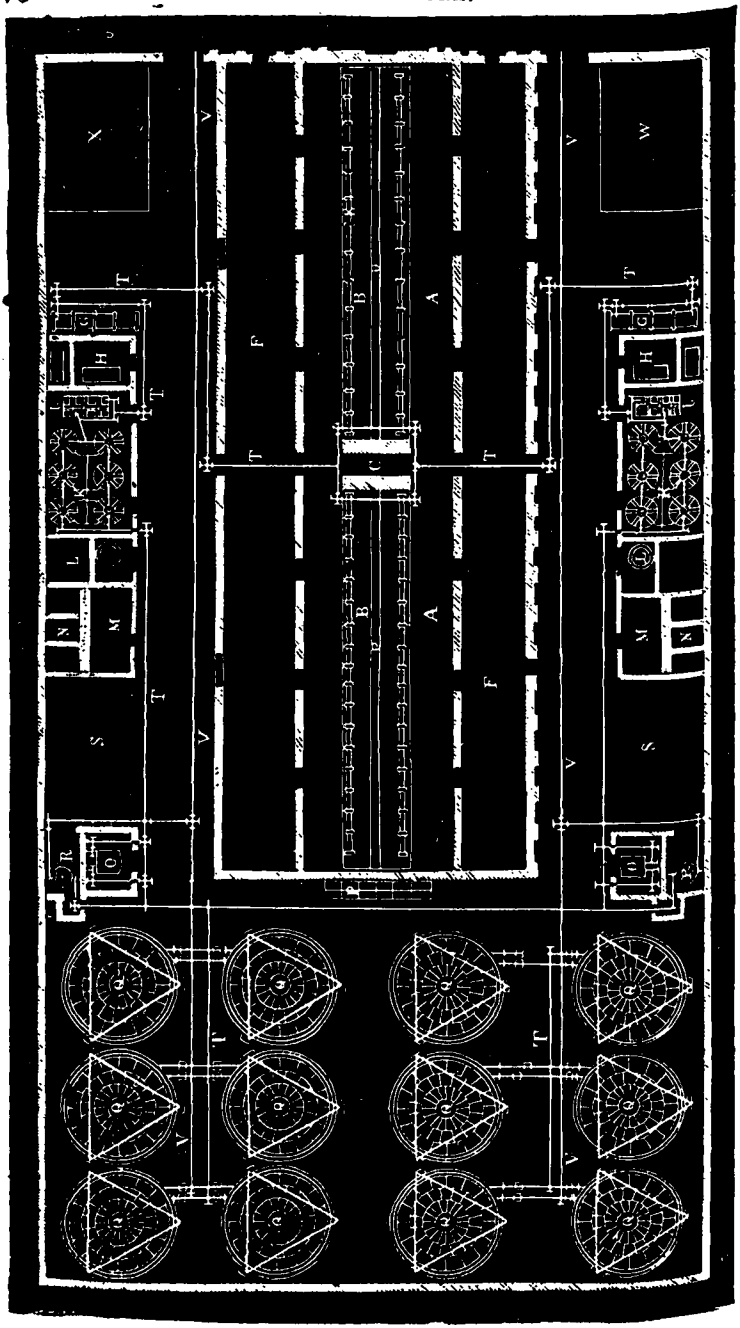
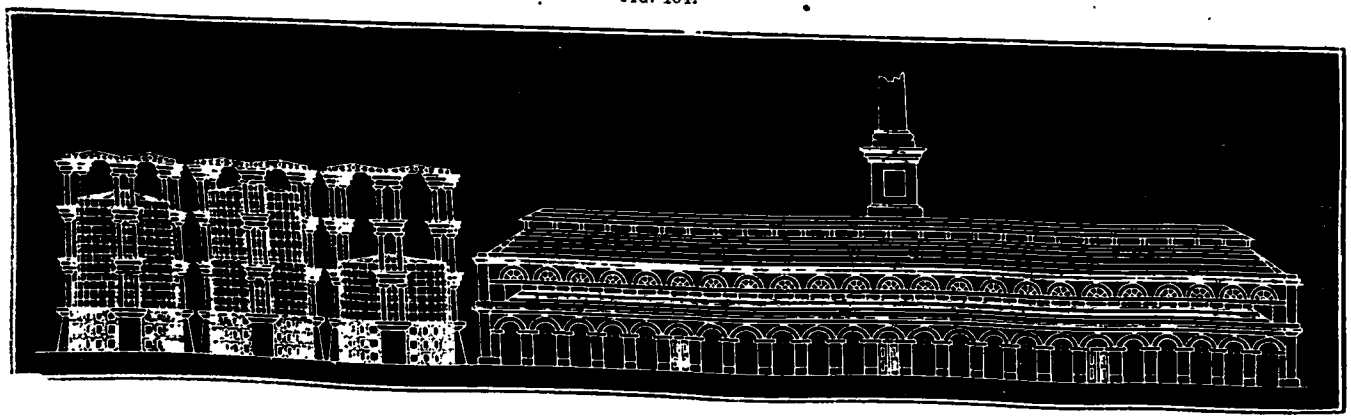


FIG. 403.

FIG. 404 IS THE SIDE ELEVATION (FRONT VIEW) OF THE GAS-WORK CAPABLE OF HOLDING 400 RETORTS, AND ALL THEIR DEPENDENCIES.

FIG. 404.



feet wide; G condensers; H engine houses; J wash vessels; K purifiers and connections; L lime store and mixing tub; M smith's and fitter's shop; N refuse lime pits; O meter houses; P tar tank; Q tanks, gas-holders, bridges, columns, valves and connections; R governor's; S coke-stoves; T inlet-pipes; V outlet-pipes; W house and offices; X stores.

Relative Value of different sources of light, and of the methods employed in evolving light.—Artificial light being essential to all classes of a civilised population, it becomes an important object to ascertain the relative value of the different modes of producing it, and of the materials employed. Every effort which tends to simplify the mode of producing light, and even the smallest abatement in price, which progressive discovery effects in this direction, is a most valuable boon to the poor; every augmentation of the brilliancy and whiteness of the light is a welcome addition to the comforts of the rich; and every improvement in the increased light of public ways and places is a benefit common to all. Without entering more minutely into the subject, it is evident that the value of any means of illumination must depend upon the *amount of light* evolved, and the *quantity of lighting material* consumed. A candle, or a lamp, &c., will be the more valuable the more light it gives from a certain quantity of tallow or oil. The consumption of illuminating material, and its price, together give the cost of the light, to which the outlay caused by the method of using the light must in many cases be added. The determination of the quantity of illuminating material consumed, as well as the calculation of its cost, is a simple matter within everybody's comprehension; the determination of the quantity of light, however, requires more explanation. Light cannot be measured or weighed like ponderable matter; it is not possible, therefore, to estimate how much light a flame emits, but it can be ascertained how much more or less intense the light from one flame is, as compared with that from another.

All determinations of this nature are, therefore, comparative. The most casual observation of two flames of equal size—for example, that of a gas-burner and a candle—shows the one to be much more intense than the other. The eye is more powerfully affected by the gas-flame; it is said to be brighter; and the impressions thus produced are attributed to the relative *intensities* or *illuminating powers* of the flames. The relations of intensity between two sources of light are considered a measure for the quantity of light

when the time is taken into consideration, or express the relation of quantity, when the time in both cases is the same.

The dissemination of light being entirely effected by radiation, the intensity is said to express the sum of the rays which are emitted to a certain surface,—for example, to a square foot. It is evident, that the number of rays must diminish with the distance from their source, as the rays diverge or separate more and more from each other. According to the laws of optics, the intensity (or sum of impinging rays) from any source is inversely as the square of the distance from their source; when, therefore, a surface is illumined to the same extent by two flames, the number of rays of light from each will be proportional to the square of the distance at which each flame must be placed in order to produce an equal amount of light. It is upon this principle that the determination of the relative intensities of different flames depends; the measure being the distance to which the different flames must be brought, in order to produce an equal amount of light. Practically, however, it is not possible to determine the brilliancy of a flame even approximatively; the light, therefore, is not observed, but the absence of light or the *shadow*; and this upon the assumption that under similar circumstances the brighter light will produce the deeper shadow. In experiments of this kind, a board covered with unglazed white paper is often used, before which, at a distance of from 2 to 3 inches, an iron rod is placed, which has been previously blackened by holding it in the candle. Opposite this board, but at the same height, the flames to be compared are so placed that the shadow from the one shall fall close to that of the other upon the board; the stronger flame is then removed, or the weaker one approached, until both shadows appear equally deep, when their respective distances from the centres of the flames are measured. The squares of these distances give the relative intensities of light: if a flame, for example, has been three times as far removed as another, its intensity will be to that of the latter as 3^2 to $1^2 = 9 : 1$, or 9 times greater. As such observations are simultaneous, and of like duration, they give likewise the relative quantities of light; for unequal lengths of time, this has only to be multiplied with the respective durations. When one of these flames, therefore, burns 3 hours, and the other only 2, then the quantities of light evolved will be in the proportion $3 \times 9 : 2 \times 1$ or $27 : 2$. Some care and practice are required in making observations on the relative value of flames, and certain precautions are necessary, which, if not

attended to, are liable to lead to erroneous conclusions. One circumstance in particular requires attention; when two perfectly similar shadows of this kind are observed from one side, the one appears brighter than the other, and the same is the case, the order only being reversed, when they are observed from the other side; so that the rule is, to observe them always from a position exactly opposite the board.

If the shadow test be taken as an indication of the quantity of light, and be made $= i$, the consumption of illuminating material being q, the formula for the *illuminating power* v will be $v = \frac{i}{q}$: an expression which, in making comparisons, shows the quantity of light for an equal amount of combustible material. The illuminating power, and the price of the material together, show the *cost or money value of the light*, which varies in an inverse ratio with the market price.

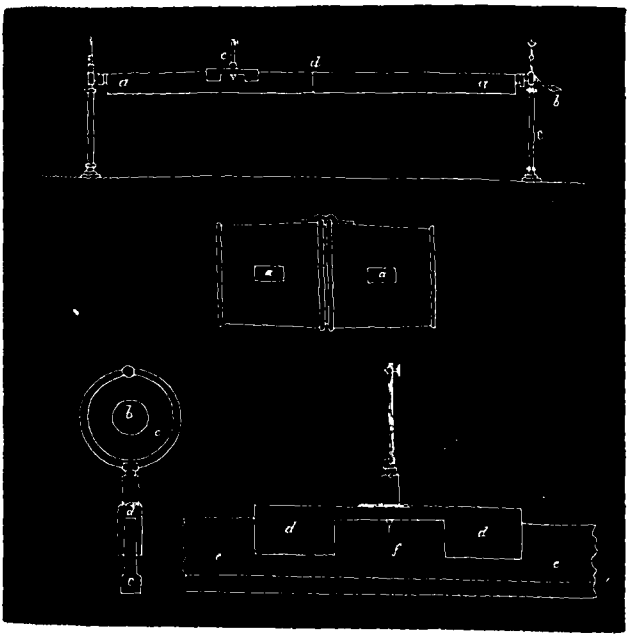
Most of the determinations given in the sequel have been made in the manner described, which is adapted for determining, not only the illuminating power of the different substances, but also the comparative value of the different modes of illumination, when the same material is employed in each case.

All determinations of the illuminating power being entirely relative, a suitable flame for comparison must be selected, which will evolve as far as possible an equal amount of light during the whole period of the experiments. No flame has yet been produced which perfectly fulfils this condition, but that of Carcel's clock-work lamp is of such very uniform brilliancy, remaining unimpaired for several hours after it has been ignited, that lamps, candles, and gas have very generally been compared with it as a standard. On comparing two exactly similar lamps of this kind in such a manner that one was kept constantly burning, while the other was ignited for each observation, it was found that the intensity of light, at first being 100, increased in half an hour to 103, in one hour to 116, and in four hours to 117, which then remained constant for four consecutive hours. The very slight change observed in the intensity of Carcel's lamp depends, as has already been explained, upon the uniform level and superabundant flow of the oil; the increase of brilliancy with the progressive burning may possibly be accounted for by the decreasing quantity of heat withdrawn from the flame by the neighbouring parts in proportion as these become warmer, and also, perhaps, by the excess of oil being too great at the com-

mencement, and becoming reduced to the proper quantity by the decreasing tension of the spring employed for working the pumps.

The photometer of Bunsen is now preferred to the shadow test by gas-engineers and others for estimating the comparative value of flames. It consists of a sheet of cream-coloured letter-paper, rendered transparent over nearly the whole surface by a mixture of spermaceti and rectified naphtha, which is solid at common temperatures, but becomes liquid on the application of a very gentle heat. The mixture is liquified and painted over the paper with a brush, leaving a round disc of the size of half-a-crown in the centre uncovered. When a light is placed on one side of the

FIG. 405.



paper, a dark spot is observed on the uncovered portion. When another light is placed on the other side of the paper, the spot is still distinctly visible if the distance of the light is such that the reflected portion from the paper be either of greater or of less intensity than that transmitted. When the paper is so situated between the two flames that the transmitted and reflected light are of the same intensity, the uncovered spot is no longer visible. The instrument is shown in Fig. 405. A clamp and frame *c d* for

holding the translucent paper-screen with the uncovered disc *b*, slides upon a perfectly horizontal beam *a a*, divided into inches and fractions; at one end of the beam the standard flame is fixed, and so regulated by a spring that it shall always be at the same height above the horizontal beam. The standard usually adopted is a spermaccti candle, of such construction and diameter of wick that 120 grains are consumed per hour. With a light of uniform intensity on the one side, the transmitted light will be of uniform intensity; and with flames of variable intensity on the other, the screen must be moved along the horizontal beam until the disc can no longer be distinguished. The squares of the respective distances of each flame from the disc will then indicate their relative values as illuminating agents. It has been found easier to judge of the condition of the screen by placing a slightly conical blackened cap on each side of it, as shown in the central drawing on Fig. 405, through an aperture in the side of which the screen can be viewed.

Illuminating power of Candles.—It is not remarkable, from the nature of candles and the mode in which they disseminate light, that their intensity and consequent power of illumination, even under the same circumstances, should be very variable. When first ignited, with the wick freshly snuffed, the variation is comparatively slight, and the intensity increases up to a certain point, until an excessive length of snuff, and deposit of spongy matter, causes a rapid diminution of the light, until the snuff is removed or the deposit burnt, when the same process is repeated. Peclet found (by comparison with Carcel's lamp) that the primary intensity of a candle (6=1 lb.) being 100, it became in 4 minutes 92, in 8 minutes 50, in 10 minutes 41, in 12 minutes 38, in 15 minutes 34, in 20 minutes 32, in 22 minutes 25, in 24 minutes 20, in 28 minutes 19, in 30 minutes 17, and in 40 minutes 14. Another candle (5 to the lb.) diminished from its original intensity, = 100, in 5 minutes to 76, in 10 to 55, in 15 to 44, in 20 to 39, in 25 to 32, in 30 to 30, in 35 to 24, and lastly, in 40 minutes to 15. Less than half an hour, therefore, is sufficient to reduce the light from a candle to $\frac{1}{7}$ of its original brilliancy. The same diminution of light was observed by Rumford, $\frac{3}{4}$ of the intensity being lost after 29 minutes. In comparing the light of candles with that of Carcel's lamp in the following pages, the mean intensity of 10 minutes' burning in tallow candles is to be understood, which is about the usual time suffered to elapse between each snuffing; in

stearine, wax, and spermaceti candles, the highest intensity is referred to, which occurs when the wick, without any deposition of snuff, has begun to emerge from the flame. Schubarth and others have compared the flames of candles with each other, instead of with Carcel's lamp, but the results thus obtained appear to be less certain.

Observations of Peclet.

Variety of Candle.	Comparison of the intensity of light.	Consumption of material in an hour. — grammes.	Relation of Illuminating Power.	
			Direct.	Carcel's lamp being=100.
[Carcel's lamp . .	100.00	42.00 rapeseed oil.	2.318	100]
Tallow candles, 6s. .	10.66	8.51	1.253	54.04
„ „ 8s. .	8.74	7.51	1.164	50.21
„ „ 5s. .	7.50	7.42	1.011	43.61
Wax „ 5s. .	13.61	8.71	1.563	67.41
Stearine „ 5s. .	14.40	9.33	1.543	66.58
Spermaceti „ 5s. .	14.40	8.92	1.614	85.68

Observations of Karmarsch.

[Carcel's lamp . .	100.00	40.30 rapeseed oil.	2.481	100.00]
Tallow candles, 6s. .	13.20	10.51	1.256	50.61
Wax „ 6s. .	14.60	9.56	1.527	61.55

Observations of Ure.

[Carcel's lamp . .	100.00	52.80 sperm oil.		1.894	100]
Tallow candles, 3s. and 4s.	8.33—6.25	9.30	grains. 144	0.896—0.572	35.5—47.3
Ditto, Palmer's . .	11.90	15.00	232.5	0.793	41.8
Wax candles, 4s., 5s., and 6s. . .	9.10	8.10	125	1.123	59.3
Stearic acid candles, 5s.	9.10	11.00	168.5	0.827	43.7
Cocoa-stearine ditto	6.25	11.00	168	0.568	30.0
Spermaceti „ 3s.	9.10	9.20	142	0.989	52.2

The importance of this tabular view is self-evident. An example will, however, show in what manner it may be used to establish the illuminating value when the market price is taken into calculation. In producing shadows of equal intensity, the tallow candle, six to the pound, was removed 3.265 feet, the wax candle 3.821 feet, and the clock-work lamp 10 feet from the shadow. The intensities, and

consequently the quantities of light, are therefore in the ratio of $3.265^2 : 3.821^2$; $10^2 = 10.66 : 13.61 : 100$ (v. Tab. Pecl.) Whilst the lamp consumed in an hour 42 grms. of oil, the candle flames required 8.51 tallow and 8.71 wax. The illuminating power is consequently in the ratio of $\frac{100}{42} : \frac{10.66}{8.51} : \frac{13.61}{8.71} = 2.318 : 1.253 : 1.563 = 100 : 54 : 67.4$ (v. Tab.) which shows the quantities of light produced by equal quantities of oil, tallow, and wax. The prices of equal quantities of these substances being as 1 : 1.42 : 4.64, the cost of a quantity of light = 100 will amount to 1 for oil, $\frac{100 \times 1.42}{54} = 2.63$ for tallow, and $\frac{100 \times 4.64}{67.4} = 6.88$ for wax. When, therefore, Carcel's lamp consumes in an evening of six hours' duration two pennyworth of oil, to obtain an equally good light during the same time from tallow 3*d.* would be the cost, and from wax about 9*d.*

The above comparison is not fully applicable on all occasions, as candles are often not sold by weight, but by the number constituting a pound. The intensity of light from a tallow candle is, from the above, to the intensity from a wax candle as 10.66 : 13,61, or as 7 : 9; 9 tallow candles must therefore be burned to produce the same light as 7 wax candles, each kind being 6 to the pound. A pound packet of the former was found in one instance to weigh 458 grms., one of the latter 426 grms., instead of 500; so that 7 wax candles weigh 596 grms., 9 tallow candles 702 grms. The 7 wax candles will cost about 2s. 5d. and burn 82 hours, 9 tallow candles will cost about 10½d. and will burn 68 hours, both with an equal amount of brilliancy, which therefore, for an equal number of hours, will cost 10½d. in tallow, and $\frac{68 \times 2\text{s. } 5\text{d.}}{82} = 2\text{s.}$ in wax. Another circumstance which influences the relative economy of the two sources of light is that the ends of candles are of much less value than the actual weight of material which they comprise, and are comparatively valueless when composed of the more costly stearine and wax.

The experiments by Peclet, cited above, merit the most confidence. A comparison of wax and stearine candles (of Berlin manufacture) with each other, which possesses much interest, particularly as regards the relative values of 4, 6, or 8 to the pound, has been furnished by Schubarth.

Kind of candles, and whence obtained.		Relative intensity of light.	Consumption in 1 hour in grammes.	Relative illuminating power.
Common wax candles of Tannhäuser	4s.	103.5	7.877	85.20
	6s.	91.0	7.176	83.20
	8s.	100.0	6.562	100.0
Wax candles of Walker	4s.	132.7	9.398	92.66
	6s.	120.3	8.082	97.69
	8s.	113.1	7.132	104.1
Stearine candles of Motard	4s.	117.4	9.427	81.74
	6s.	111.8	9.383	78.23
	8s.	121.0	7.877	100.7
Stearine candles of Maquet and Oehmichen	4s.	139.5	10.63	86.11
	6s.	132.7	9.398	92.66
	8s.	125.0	8.506	96.54
Stearine candles from the same makers	6s.	116.1	8.871	85.86
	8s.	146.0	8.886	108.0
Candles made from palm oil	4s.	124.5	9.880	82.67
	6s.	115.3	9.178	82.56
	8s.	167.5	8.813	113.70

Thus it appears that with reference to the hourly consumption it is not unimportant whether 4, 6, or 8 candles make up the pound. Of the last, the smallest quantity is consumed, more of the sixes, and most of the fours. While 1 lb. of wax candles, 8 to the pound, burn 62 hours, 1 lb. of sixes burn, on an average, only 55 hours, and 1 lb. of fours only 48 hours. In the same order, 1 lb. of stearine candles will burn 57, 49, and 45 hours. The intensity of the light also varies, being greatest in candles 8 to the pound, less in sixes, and least in fours, about in the proportions of 15 to 12 and 10. According to the foregoing experiments, the mean illuminating power of wax and stearine candles is nearly the same. This result, without influencing the general conclusions, does not agree with the very accurate and often-repeated experiments of Karmarsch, who found the illuminating power of wax candles to be ¼ greater. As a general fact, it may be assumed that the estimation of the intensity of the light, and of the time during which a candle is capable of burning, is sufficient to determine its value as a source of light in comparison with other candles, without knowing the weight which is consumed in an hour. The true weight and the nominal weight are always different in a candle, so that a wax candle (8 to the pound, for instance), instead of weighing 66 grms. only weighs 52, and so with others. According to Fyfe, a spermaceti candle burns 8 hours, a wax candle 9 hours, with equal intensity of light: in order, therefore, to produce this intensity for an equal length of time, 65 wax candles, or 72 spermaceti candles ($=8\frac{1}{8} : 9$), must be burnt. When, therefore, the price of the

wax is 3½ times that of spermaceti, their illuminating values will be inversely as:—$65 : 3.5 \times 72 = 1 : 4$ nearly. Möhr found the illuminating power of spermaceti candles to that of wax candles as 86 to 100; which, when the relative prices are as above, makes the cost of light from wax 5 times dearer than from spermaceti, while, according to Peclet, instead of 5, it was only 3 times more. This difference in the results might have been anticipated to a certain extent on account of the fluctuating light of the candles. Although the relative values of different kinds of candles cannot be ascertained with mathematical accuracy, yet such experiments are always valuable as approximations.

The following comparative value of candles has been drawn up by Karsten from experiments undertaken to test the value of the paraffin candles made by Wiesmann and Co. of Bonn:

Kind of Candles.	Grains of material consumed in 4½ hours.	Light from an equal amount of material.	Illuminating value, or light obtained for a certain fixed amount of expenditure.	Relative price of material.
Paraffin .....4 to the lb.	525	1.00	1.00	30
Spermaceti .....6 ditto ...	540	0.826	0.62	40
Wax .....4 ditto ...	552	0.45	0.519	26
Artificial wax .....5 ditto ...	642	0.76	1.086	21
Ordinary stearic acid .....4 ditto ...	822	0.543	1.018	16
Tallow.....6 ditto ...	1020	0.45	1.35	10

It thus appears that paraffin at present prices cannot compete with tallow and some of the finer material for candles; but its great beauty, which is quite comparable to wax, and its perfect combustion without waste, may be set against its somewhat greater cost.

Why, it may be asked, are the means of increasing the steadiness and power of the flame, which have been described with reference to the Argand burner, not applied to regulate the light of candles? The level of a candle-flame is constantly changing with the consumption of the material, so that mechanical contrivances must be resorted to, either to lower the glass cylinder—if such be employed—or to retain the flame at a constant height. It is, however, difficult to apply contrivances of this kind without interfering with the great simplicity which is the chief recommendation in the use of candles. But supposing this difficulty surmounted, glass chimneys for regulating the draught could not even then be used, for as soon as a glass of this kind is applied, the flame gra-

dually diminishes until it is completely extinguished, and this happens more quickly with wax and stearine than with tallow candles. The cause of this is obvious. Two-thirds of the flame at least must enter the chimney if the latter is to exert any action whatever; the draught is then very much increased around the flame, just as was the case with lamps, and greater brilliancy and steadiness result for the first minute or two; but the current directed against the base of the wick will, in the next minute, cool both it and the adjacent parts so much, that the supply of fat is stopped. The reservoir and lower part of the wick, instead of being filled with a store of melted fat, become empty and dry, the flame shrinks together, and retreats to the highest point of the wick, in which position the evil is only magnified. As soon as the glass chimney is removed, the flame again assumes its original size. The use of such a chimney would, therefore, only be practicable with a supply of hot air.

Illuminating power of Oils.—The illuminating power of lamps depends not only upon their construction, but also upon the nature of the material consumed in them. In northern countries the materials employed are whale oil, train oil, and especially rape-seed oil; in the south, olive oil of inferior quality is used, to which may be added here and there the fluid fats obtained as a secondary product in the manufacture of stearine and stearic acid. The illuminating power of these oils has not been so repeatedly and accurately examined, as the importance of the subject merits, although the method to be pursued is simple and not attended by much difficulty. It consists in filling the same lamp, under similar conditions, with the different oils consecutively, the illuminating powers of which are to be tried; all differences in this case can only arise from the nature of the illuminating material.

Dr. Ure using a Parker's economic lamp, obtained the following results:—

	Intensity.	Consumption in 1 hour in		Consumption in 1 hour, intensity = 100.	
		grms.	grains.	grms.	grains.
Sperm oil . .	121	47.6	696	39.5	576
Southern whale oil	82	50.5	780	59.0	911
Olive oil . .	90¼	53.2	760	54.4	840
Oleine from the cocoa-nut .	81	66.7	1035	82.7 44	1217

whence it appears, without taking price into consideration, that sperm oil is superior to all others.

The high price of rape oil in unproductive seasons gives rise to its being mixed with the cheaper linseed oil, in which adulterated state it is frequently met with in commerce. Linseed oil, on account of the property it possesses of thickening, cannot be used alone in lamps, and when mixed with other oils it causes the flame to smoke or burn with difficulty. The eulogiums passed upon sweet or olive oil as an economical source of light induced Karmarsch and Heeren to test its illuminating power very carefully as compared with that of rape-seed or Colza. Two lamps of like dimensions and constructed with Argand burners afforded a means of direct comparison; all precautions were taken to secure accuracy, and the glass chimneys changed about to avoid all possibility of their exerting any special influence. The first series of experiments, as the mean of twelve observations, gave for olive oil, an intensity of 1066 with a consumption of 460.9 grms. in nine hours and a half; for rape oil an intensity = 1000, with a consumption of 428.4 grms. in the same time. In a second series the mean of nine observations showed the intensity produced by olive-oil with a consumption of 359.5 grms. in eight hours to be $\frac{980}{1000}$ of the rape-oil, of which 367.2 grms. were consumed. According to the former experiments, therefore, the illuminating power of olive-oil, as compared with rape-oil, is as—

$$\frac{1066}{460.9} : \frac{1000}{428.4} = 2.313 : 2.334;$$

according to the latter, as—

$$\frac{980}{359,5} : \frac{1000}{367,2} = 2.726 : 2.723.$$

From equal quantities of both oils, an equal quantity of light is therefore evolved, but from olive-oil in a shorter time, because it gives proportionally more light, as more of it is consumed.

The importance of purifying oil for burning, from all foreign matters, particularly albuminous matter (mucus), as was noticed above, is very clearly demonstrated by the experiments of Kaiser, which unfortunately had reference only to the consumption and not to the intensity of the light. A lamp without wick, like Fig. 258, was supplied alternately with purified and crude oil, and the

time and amount of consumption noted. In this manner 2 grms. of purified oil were consumed, 1.82 grm. of warm drawn, and 1.6 grm. of crude oil. Hence 100 grms. of the first would burn 50 hours, of the second 55½, and of the last 62½. As long as the quantity of light evolved at the same time is unknown, it is impossible to form an opinion respecting their relative values.

Illuminating power of Lamps.—A perfectly uniform light cannot be obtained from lamps, on account of their construction, and more particularly from the action of the wick; the variations, however, which occur in the intensity of the light are confined within much narrower limits than in the case with candles, where a constant change is occurring, while it is only a gradual diminution in lamps. This diminution has already been stated for Carcel's lamp. A single observation or the mere knowledge of the mean intensity of light gives a very imperfect idea of the action of a lamp; the diminution in brilliancy during a whole evening, or during about six hours, must always be observed. Peclet, as well as Karmarsch and Heeren, have given, as an addition to their experiments, tabular statements of this diminution, both of which are here inserted.

Experiments by Peclet.				Comparison of the diminution of light.						
	Dimensions of the wick, breadth or diameter.			Intensity of light.						
Kind of lamps.	Internal.	External.	Distance of the oil from the margin of the burner.	In the 1st hour.	In the 2nd.	In the 3rd.	In the 4th.	In the 5th.	In the 6th.	In the 7th.
	Lines.									
No. I. Lamp, with flat wick and chimney	7.2			100	100	98	98	97	96	96
— II. Astral lamp	4.6	8.8		100	103	90	72	61	42	34
— III. Sinumbra lamp	6.4	11.2		100	102	95	83	81	78	60
— IV. „ with intermittent oil level	„	„	2.8	100	100	90	70	52	41	32
— V. Lamp with inverted reservoir, and Sinumbra burner	3.6	10.0	2.8	100	100	97	95	92	89	86
— VI. Lamp with inverted reservoir	4.4	10.4	8	100	103	82	79	75	72	65
— VII. Girard's lamp	2.64	6.8	8	100	101	96	84	81	76	70
— VIII. Thilorier's No. 1.	6.4	11.2	2	100	106	103	100	94	92	90
— IX. Ditto, No. 4.	2.64	6.8	2	100	101	101	101	100	98	96

Compared with each other with reference to their illuminating power, the same lamps gave the following results :—

Number of the lamp.	Average intensity of light during seven hours, Carcel's lamp = 100.	Consumption in one hour in grammes.	Quantity of light from 100 parts of oil, Carcel's lamp = 100.	Number of the lamp.	Average intensity of light during seven hours, Carcel's lamp = 100.	Consumption in one hour in grammes.	Quantity of light from 100 parts of oil, Carcel's lamp = 100.
Carcel's lamp	100	42.00	100.0	No. V. . .	41	18.00	95.4
No. I. . . .	12.5	11.00	47.5	— VI. . .	90	43.00	87.8
— II. . .	31	26.71	48.7	— VII. . .	63.7	34.77	* 76.5
— III. . .	56	37.14	63.0	— VIII. .	107.7	51.14	90.3
— IV. . .	85	43.00	82.8	— IX. . .	45.0	17.26	109.2

The observations of Karmarsch and Heeren were made upon exactly the same principle, and are to be understood in the same manner. The first column in the following table gives the dimensions of the lamps used by them.

Sort of lamp.	Breadth of the wick, or diameter of the burner.		Average intensity of light from twelve experiments.	Consumption of rapeseed oil in one hour in grammes.	Quantity of light from an equal quantity of oil, Carcel's lamp = 100.
	Inner.	Outer.			
	Lines.				
No. I. Carcel's clock-work lamp.....	6.8	9.2	100	40.64	100
— II. Kitchen lamp	3.2 (thick)		6.65	8.05	33.58
— III. Lamp with flat wick	8.2 (broad)		15.13	9.40	65.71
— IV. Lamp with chimney	7.6		19.37	12.33	63.82
— V. Table lamp with circular oil vessel, and semi-circular wick	12.5		32.64	20.88	63.54
— VI. Astral lamp.....	6.2	9.4	44.98	28.70	63.72
— VII. Sinumbra lamp.....	5.2	8.8	52.50	26.74	79.78
— VIII. Lamp with flat wick, and inverted reservoir	8.4 (broad)		21.50	14.90	54.80
— IX. Wall lamp with inverted reservoir, and semi-circular wick.....	13.0	„	39.33	20.15	79.35
— X. The same with round wick	7.4	10.0	52.54	29.33	72.81
— XI. Liverpool lamp with inverted reservoir.....	6.0	9.2	41.80	26.78	63.45
— XII. Wall lamp with constant oil level and regulator*	5.8	8.0	82.46	35.44	111.60
— XIII. Hydrostatic lamp	7.4	9.2	92.44	38.94	113.90

* This French lamp combines the advantage of the inverted reservoir with that of a contrivance similar to Caron's stop-cock, which obliges the oil to rise to such a height in the burner, that when the opening is unimpeded, and the flame extinguished, it still continues slowly to flow out.

With Lüdersdorff's vapour lamps the same observers found:—

Dimensions.	Intensity of light when half the time had expired.	Consumption of material in an hour.	Illuminating power.
No. I. With twelve holes 0.4 lines apart in a circle of 1 inch diameter ...	130.7	560 grms. of illum. spirit	36.2
— II. With twelve holes 0.4 lines apart in a circle of 13.6 lines diameter	69.6	315 „ „	34.2
— III. With eight holes 0.4 lines apart in a circle of 10.9 lines diameter	52.8	295 „ „	27.7
Carcel's lamp.....	100.0	155 rape-oil.	100.0

Lastly, an observation of Ure's upon Parker's lamp may be given:—

Lamps.	Intensity of light.	Consumption of sperm oil per hour in grammes.	Quantity of light from the same quantity of oil.
Mechanical lamp	100	52.7	100
Samuel Parker's lamp.	121	45.1	141

The first table presents some remarkable facts with reference to the diminution of the intensity of light. With the lamps in which the oil level gradually sinks, the diminution is greatest in No. II.; and only very slight in No. I., where a greater difference might have been looked for. It was also to be anticipated that the lamp No. III. should show less diminution of light, when, with the same dimensions, the level of oil in its burner is rendered constant by an annular reservoir, after the fashion of the inverted vessels in No. IV.; and yet such is not the case according to the table. Thus in both No. I. and No. III. other influences must preponderate, which assist in retaining the more uniform brilliancy of the flame. On the whole, the diminution of light in six hours amounts to $\frac{1}{2}$, $\frac{1}{3}$, and even $\frac{1}{4}$ of the original intensity: it is only imperceptible in Carcel's and Thilorier's lamps, and both these produce their light with the least consumption of oil, while the lamp with a flat wick requires the largest quantity.

The following table contains the results of some recent experiments by Karsten upon the illuminating value of different materials :—

Material, and mode of employing it.	Intensity.	Consumption in grammes per hour.	Quantity of light from equal quantities of material.	Quantity of light for a certain fixed amount of expenditure.	Cost of an equal amount of light.
Müller's oil lamp	1.0000	23.78	1.0000	1.0000	1.0000
Photogen lamp	.8420	17.33	1.1550	0.5510	1.8149
Tallow candle (8 to the lb.)	.2625	11.33	0.5507	0.3442	2.9052
Stearic acid candle (8 to the lb.)	.1615	7.00	0.5628	0.1759	5.6850
French moderator lamp	—	—	0.9530	0.9530	1.0493
Study lamp with oil, on Müller's principle...	—	—	0.7780	0.7780	1.2853
Ordinary flat-wick'd lamp	—	—	0.5400	0.5400	1.8518
Lamp consuming spirit of wine and oil of turpentine (Lüdersdorf's)	—	—	1.1820	0.5260	1.9011
Wax candles (6 to the lb.)	—	—	0.4640	0.0967	10.3412

Of the construction of Müller's lamp, which is evidently the cheapest source of light, according to these experiments, we have been unable to obtain any information.

The photogen is a mixture of alcohol with coal-tar naphtha, and is burned, we apprehend, in the same manner as the gasogene described at a former page, upon Lüdersdorf's principle. It was with a view to test the value of this mixture as an illuminating material that the experiments were made. It will be seen that the French moderator lamp falls little short of Müller's as a source of cheap light, while the brilliancy of the photogen and of Lüdersdorf's lamps is only attained at considerable expense; and as alcohol is one of the ingredients in both the fuels for these lamps, the relative cost of the light would be very much increased in Great Britain, where the price of alcohol is much higher than in any of the continental states.

The irregularities and apparent contradictions in the action of lamps can only be properly understood and explained by weighing the influence of different secondary causes. The whole art of constructing good lamps depends upon a proper relation being established between the current of air and the flow of oil. Although the mobility of the wicks and chimneys assists in establishing this condition, yet even the better kinds of lamps are still very far removed from it. The position of the wick,

downwards, can never exceed a certain limit, for it must always project so far from the burner that in a certain time as much oil shall enter into combustion as is requisite to produce the amount of light necessary. For this reason, it is desirable to be able to control the air supply, and suit it to a certain fixed position of the wick, and not to move the wick at all. The width and height of the glass chimney bring the draught quite under control; yet the quantity of air conducted to the flame in lamps is, in nearly all cases, too great: the flame has, consequently, to warm a portion of this air at the expense of its own temperature and intensity; and from this portion no advantage is derived. The chimney, which can only be made of glass, must be wide, to lessen the chance of fracture, although the danger is often overrated, and the glasses are seldom made sufficiently narrow—though undoubtedly they are then exposed to a much higher temperature. The current of air may likewise be diminished by contracting the mouth of the burner, through which it enters the chimney. When, according to Peclet, 100 grms. of oil produced an amount of light = 1000, with a burner in which the space for the internal current was 6.4 lines wide, this quantity was increased to 1014 when the draught aperture was 4.8 lines, to 1093 when it was 3.6 lines, and 1209 when only 2.4 lines in width. Very small air-apertures, on the contrary, give rise to too much friction, and require an increased power of current. The proposition for supplying the internal and external air-holes with dampers which can be moved according to circumstances, would certainly be desirable, but has seldom been put in practice. Holthouse found that an excessive height of chimney, for example 3 feet to $\frac{1}{8}$ inch in width, caused the flame to flicker, but that the greatest steadiness was obtained when, the width remaining the same, the height was 7 inches. The aim of recent improvements has been directed to the deflection of the air-current, without much attention to the quantity supplied. This part of the subject was discussed at pages 489—493. The advantage of the cone for deflecting the air-current in lamps was at first much overrated, until carefully examined by Karmarsch and Heeren. Numerous carefully conducted observations with these lamps,—which, without the appendage *d*, Fig. 282, p. 490, were converted into common Argand's lamps,—under conditions favourable to complete combustion, gave the following results. Experiments were made with three lamps, No. I. having a breadth of burner = $\frac{7}{8}$ inch, No. II. = $\frac{9}{16}$ inch, and No. III. = $\frac{7}{16}$ inch.

	Intensity of light.		Consumption.		Consumption for an intensity of light = 1 tallow candle.	
	With	Without	With	Without	With	Without
	Cone.		Cone.		Cone.	
No. I.	1334	739	19.50	12.62	100.0 :	95.0
— II.	656	336	8.94	5.37	100.0 :	105.2
— III.	392	146	5.75	3.37	100.0 :	80.0

Two perfectly similar lamps, with inverted reservoir and $\frac{7}{8}$ of an inch width of burner, showed an intensity of light, without the cone, $\leq$ 1000, and the consumption was = 14.56; while the intensity with the cone was = 1334, and the consumption 19.5; whence the actual illuminating value was as—

$$\frac{1000}{14.56} : \frac{1334}{19.5} = 68.4 : 68.7.$$

These examples, together with numerous others by the same observers, prove, beyond a doubt, that with wider burners, (above $\frac{1}{2}$ inch), in Benkler's lamps, the production of an increased amount of light is attended by a corresponding consumption of oil, which is also the case in well-arranged Argand lamps of ordinary construction: with narrower wicks it appears, however, that they are somewhat more economical. In all cases, the intensity of the light, with Benkler's cone, was found considerably (sometimes doubly) greater than in lamps without it; but the consumption being nearly in the same ratio, there is but little difference in actual illuminating value. Benkler's lamps are excellent for producing a very white light, quite equal to that of gas (hence called gas lamps), and for their steadiness of flame, which is quite unaffected by draughts of air in the vicinity, or by the motion of carrying. Narrow burners are also preferable on account of the light they evolve being perfectly uniform during 4 or more hours, while wider burners show a rapid diminution, and easily begin to smoke when not regulated by altering the height of the wick. A lamp with a wick $\frac{3}{16}$ of an inch in diameter, with a flat oil vessel, and no inverted reservoir, gave at first an intensity of light = 185; after an hour this rose to 240, in another hour to 268, and after a third hour it was still as high as 235. The intensity of another lamp, on the contrary, the wick of which was $\frac{2}{3}$ of an inch in diameter, diminished from 748 and 869 in the first and second hours, to 634 and 603 in the third and fourth.

Where several of Benkler's lamps are used together in the form of a chandelier or otherwise, as in large rooms, workshops, &c., the evolution of heat from the lamps raises the temperature very perceptibly. A middle-sized lamp, the chimney of which is 1 foot high, with a contraction 0.6 of an inch in width, immediately melts a bar of zinc held over it. The temperature at that spot cannot, therefore, be less than 360° C. (680° F.), according to which 1.5 C. F. of air (at 360° C.) must pass through the cylinder in one minute; but this is much below the actual quantity.

Benkler's lamp also admits of more oil being burnt in the same time with the same wick, or the wick may be raised much higher above the burner. For producing an equal intensity of light, the lamps may therefore be of smaller dimensions, and are consequently less costly. On the other hand, the carbonization of the wick is so considerable, that thick wicks must never be used. Train oil and unclarified oil, contrary to the assertion of the inventor, cannot be used in these lamps without depositing carbon on the wick, as is the case with other lamps.

Both wick and cone *d* being of the same diameter in Benkler's lamp, it is obvious that by raising the former more oil must be brought into the sphere of combustion, while the external draught is diminished in proportion as the distance of *d* from the wick is lessened. In the highest position of the wick, when the outer current of air ceases entirely, the disproportionate supply of air and the great cooling influence exerted by the ring upon the summit of the wick give rise to a singular phenomenon. The internal current of air is only just sufficient to keep up the weak blue flame below the ring, while the flame above is extinguished, its place being occupied by a smoking current of gas, which can be re-ignited at the apex, where it again comes into contact with the external air. This slightly luminous point flickers over the current of invisible gas proceeding from above the ring, assuming the form of narrow flames below.

The same amount of light being evolved from equal quantities of oil in Benkler's lamps as in those of ordinary construction, appears strikingly opposed to the great luminosity and beauty of their flame. Many improvements introduced with a view of producing light of greater intensity, have failed in consequence of this increased consumption of material. The advantage derived from increased intensity (produced by means similar to those in Benkler's lamp), when carried beyond a certain point, is counter-

balanced by a diminution in the size of the flame, and consequent contraction of the radiating surface. In an ordinary lamp this surface is extensive, and only slightly luminous, while in Benkler's it is small, and more powerfully luminous in proportion.* An extension of flame-surface, as in the Liverpool lamp, has, therefore, its advantages over the contraction, as in Benkler's. For the same reason tall chimney-glasses, which produce a greater draught, cease to be of advantage when they diminish the size of the flame as much as they increase its brilliancy.

The position of the wick exerts much influence upon the proper action of every lamp, because the consumption of oil does not increase in proportion to the size of the flame, and the latter is immediately dependent upon the position of the wick. According to Peclet, the quantity of light produced by equal quantities of oil was—

	In a lamp with a flat wick.	In the hydrostatic lamp.	In the sinumbra lamp with intermitting level.
At the greatest height of the flame without smoking	100	100	100
At a medium height	64	74.4	92
At its lowest ditto	43	25.5	45.5

It is not advisable to employ the largest possible flame, because the least thing then causes it to smoke and flicker, and the wick becomes very soon charred. Large flames do well, however, when the correct proportion between the supply of air and of oil is attended to. Much also depends upon the width of the annular space in the burner for the wick. Where the space for the oil is very large, or the oil is contained in an open vessel, the wick becomes charred to the very surface of the oil, and finally remains in the flame like the snuff of an unsnuffed candle, while in narrow burners a white uncharred ring always remains above the margin, although the intensity of the light soon diminishes. A proper medium between these extremes can be preserved by making the annular wick-holder

* The flame of the former is somewhat cylindrical, that of the latter acutely conical. Supposing that an ordinary flame, 1 inch in diameter and 1.5 inch in height, gave as strong a light as one of Benkler's, 0.5 in diameter and 3 times the height, the corresponding surfaces would be in the proportions of about 19 to 10. In addition to this, the imperfect transparency peculiar to every flame increases in Benkler's with its diminution in size, and more of the light from the posterior half is absorbed by the anterior part than in ordinary flames.

wide, except at the distance of about a line from the margin, where it is made narrow.

Illuminating Power of Gases.—The illuminating power of gas has generally been estimated by the shadow-test, or by Bunsen's photometer, in conjunction with an experimental meter for accurately measuring the consumption. The standard of comparison used by different experimenters has not always been the same, but a spermaceti candle, consuming 120 grains per hour, is now generally adopted.

Illuminating gas must vary in illuminating power with the proportion of carbon it contains; but much must depend upon the mode of combination in which the carbon is present, and also upon the manner in which the gas is burned. Thus carbon, in the form of carbonic acid, is not only useless as a source of light, but actually prejudicial, a very small proportion of carbonic acid in coal-gas reducing the illuminating power to a great extent. Carbon, in the form of carbonic oxide, and as light carburetted hydrogen, is of little or no value as a source of light, these gases burning with a very faint flame. The heavy carburetted hydrogens, as olefiant gas, oil-gas (C_8H_8), and the vapours of naphtha, many and indeed most of which are condensed by chlorine, bromine, and anhydrous sulphuric acid, are the ingredients of coal-gas to which it owes its illuminating power. Hence the value of gas as an illuminating agent has, since the time of Henry, been frequently estimated by the amount of condensation which it undergoes when mixed with a sufficient quantity of chlorine to absorb these higher compounds of carbon with hydrogen. Dr. Fyfe relies most implicitly upon the condensation test by chlorine, in connection with what he terms durability, for an accurate indication of the value of any gas, and he has shown that in a great many instances these two points give a value which agrees very well with carefully conducted photometrical experiments. By durability is to be understood the time during which a certain volume of gas will continue to afford a standard amount of light. Bromine is employed by many to replace the chlorine in condensing the heavy carbohydrogens, and is in many respects more convenient for manipulation. In both cases the vapours of these substances left after condensation require to be removed from the gaseous mixture by a solution of potash before the amount of condensation is estimated. Anhydrous sulphuric acid, obtained by warming the Nordhausen acid, is preferred by others for effecting this condensation, a ball of porous

coke attached to a platinum wire being saturated with the acid and thrust up into the mixture of gases. The substances condensed from the gas by all these agents appear to be the same; but from what has been stated with reference to the nature of these condensed hydrocarbons from different specimens of coal-gas, the illuminating power of the gas must depend far more upon their chemical constitution, and upon the amount of carbon which they respectively contain, than upon the volumes which they occupy before condensation; and hence, although the test may be a good one when applied to gas obtained from the same species of coal under like conditions, and containing the same kinds of hydrocarbon, it is not applicable as a means of setting a value upon gases obtained under different circumstances from different species of coal.

The substances condensed by these reagents are probably similar, if not identical in composition with those condensed from oil-gas and resin-gas. Mr. Lewis Thompson has ascertained, by comparing the density of ordinary Newcastle coal-gas before and after condensation by bromine, that the vapours of the light-giving portions have a specific gravity ranging from 2.8 to 3.3.

The liquid condensed from resin-gas by M. Couerbe yielded six fluids, the nature of which, with the calculated and experimental densities of their vapours, are given in the following table:—

		Density of Vapour.	
		Calculated.	Found.
No. 1.	$C^4 H^4$ . . .	1.763	2.000
2.	$C^5 H^4$ . . .	2.385	2.254
3.	$C^6 H^4$ . . .	2.806	2.802
4.	$C^7 H^4$ . . .	3.230	3.340
5.	$C^8 H^4$ . . .	3.660	3.765
6.	$C^{28} H^{22}$ . . .	2.665	2.637

The first of these has a specific gravity about equal to the condensable matter in Wigan Cannel and Ramsay's Cannel, while the third and fourth resemble that from Pelaw, Pelton, and other Newcastle coals. A more elastic vapour probably remained in the gas from which these substances were condensed, which would have a lower specific gravity, and come to resemble the condensable matters in Boghead and Lesmahago cannel-gas. The specific gravity of the condensable matter from these gases may be seen

from the following table by Mr. Evans, of the Westminster Gas-works:*—

Table of Yield of Cannel Coals, and Illuminating Power of the Gas.

Name of Coal.	Gas, per ton.	Condensed per cent. by bromine.	Specific gravity of gas.	Specific gravity of condensed matter.	Photogenic power.	
					Actual.	By analysis.
Boghead	15,000	30.	.752	1.21	37.75	36.3
Lesmahago, No. 1	13,500	16.	.642	1.64	27.1	26.24
Ditto No. 2	13,200	17.	.618	1.43	24.8	24.31
Capeldrae	14,400	16.5	.577	1.29	19.75	21.28
Arniston	12,600	17.	.626	1.40	22.50	23.80
Ramsey	10,300	12.5	.548	1.82	21.40	22.95
Wemyss	14,300	14.5	.580	1.87	24.50	27.11
Kirkness	12,800	10.2	.562	1.95	21.20	19.88
Knightswood	13,200	9.5	.550	2.28	19.00	21.66
Wigan (Ince Hall)	11,400	11.5	.528	1.77	20.00	20.35

The following table† shows the Illuminating Value of the Gas obtained from Newcastle Coal, and may serve as a fair indication of the character of the gas supplied in the metropolis:—

Name of Coal.	Gas per ton.	Illuminating power.	Specific gravity of gas.	Condensation per cent.
Pelton	11,000	14.0	.430	4.5
Ditto Cannel	11,500	18.5	.520	10.5
Leverson	10,800	12.5	.425	4.
Ditto Cannel	11,600	18.	.523	10.
Washington	10,000	14.	.430	5.
Ditto Cannel	10,500	18.	.500	10.5
Pelaw	11,000	12.75	.420	4.5
New Pelton	10,500	12.	.415	4.75
Dean's Primrose	10,500	13.5	.430	5.
Garesfield	10,500	11.5	.398	3.75
Gosforth	10,000	12.	.402	4.
West Hartley	10,500	12.5	.420	4.2
Hastings Hartley	10,300	12.5	.421	4.3
Blenkinsop	9,700	14.	.450	6.

The only sure method of arriving at the actual amount of carbon in a gaseous mixture, and at the same time showing the character of the carbonaceous compounds contained in it, is to combine the condensation method with an organic analysis, or by the old plan of combustion with oxygen, as proposed by Henry, noting the quantity of oxygen consumed, and the amount of carbonic acid produced. Thus, a known volume of coal-gas is mixed

* Journal of Gas-lighting. † Ibid.

with an excess of oxygen and exploded, the amount of carbonic acid produced and of oxygen consumed being ascertained. Another equal volume is then treated with an absorbent, as anhydrous sulphuric acid, and after the products of the absorption have been removed, the residue is again mixed with oxygen, and exploded; the amount of carbonic acid being again ascertained, and deducted from the quantity obtained by exploding the original gas: the quantity of carbon contained in the condensed portion of the gas being thus ascertained, its value as an illuminating agent may be calculated accordingly. There appear to be some compounds of carbon and hydrogen in certain coal-gases different from light carburetted hydrogen, and which are not condensed by any of the absorbents named, and which, nevertheless, add much to the illuminating power; so that calculations based upon the above method of analysis will prove rather below than above the true value of the gas.

In estimating the value of gases by the photometer, it is absolutely necessary to burn the gas in a great variety of ways,—with differently constructed burners, in different quantities, and under varying amounts of pressure,—in order to ascertain under what conditions it affords its full value as an illuminating agent. A gas which is very rich in heavy hydrocarbons cannot be burned to advantage with a burner adapted for less rich gas,—the apertures require to be smaller, in order to bring more oxygen into contact with each flame; and a poor gas, on the contrary, burned in a manner suitable for rich gas, will not afford its maximum effect, in consequence of too much air being brought into contact with the flame.

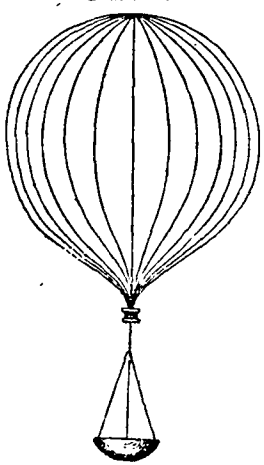
If the central ring of an Argand burner, consuming oil without smoke at its maximum degree of brightness, be closed so as to exclude the inner current of air from the flame, the brightness is visibly diminished, but, strange as it may appear, the amount of light, as indicated by the photometer, is increased. A greater number of the particles of carbon are rendered luminous before being consumed, by diminishing the supply of air in this manner,—and a greater quantity of light diffused, although the light is not so brilliant. By increasing the supply of air, much of the carbon is consumed at once, without taking a solid form in the flame; more heat is then produced, and those particles which are solid in the flame are more intensely heated: quantity of light is then sacrificed

to intensity. Gas has little tendency to smoke. It is generally better suited to the production of intensity than quantity of light; and for this reason, in comparing the illuminating power of different gases with each other, it would be better to adopt as a standard the flame of some gaseous mixture of known composition, instead of the spermaceti candle, which is calculated for affording quantity rather than intensity of light.

The more carbon there is contained in gas the heavier it is, and specific gravity has therefore been often resorted to as an indication of the relative values of different gases. If carbonic acid has been completely separated, and no excess of carbonic oxide is present, the specific gravity may furnish an important indication to the manufacturer, of the value of gas made under similar circumstances, but it can never replace an analysis in judging of the value of different gases, as the amount of carbonic oxide will vary with the kind of coal used, and the method of conducting the distillation, the specific gravity of which is very nearly equal to that of olefiant gas.

Mr. Wright employs a small balloon, Fig. 406, capable, when filled, of holding 1000 cubic inches of gas, which is gauged by a ring fitting its largest diameter when full. The weight of the balloon and car being known, and the air expelled, it is filled with gas; weights are then placed in the car until it remains in equilibrium in the air. The data thus obtained, with corrections for temperature and pressure, afford an approximate means of ascertaining the specific gravity of the gas. Mr. Wright has constructed a table, by simple reference to which, and a knowledge of the weights required to balance the balloon, the specific gravity may be read off for any variations of temperature and pressure. Little reliance is, however, placed by gas engineers upon any test of illuminating power based upon specific gravity, as this is often considerably increased by the presence of carbonic acid and carbonic oxide, which adds to the weight without increasing the illuminating power of gas.

FIG. 406.



Christison and Turner observed the following relations between the specific gravity and illuminating power of coal- and oil-gas :—

Specific gravity			Relation of illuminating power		
Of coal-gas.	—	Of oil-gas.	Of coal-gas.	:	Of oil-gas.
0.659	—	0.818	100	:	140
0.578	—	0.910	100	:	225
0.605	—	1.110	100	:	250
0.407	—	0.940	100	:	354
0.429	—	0.965	100	:	356
0.508	—	1.175	100	:	310
0.529	—	0.986	100	:	272 average.

According to a report made by Hedley to Parliament, the illuminating power of coal-gas, in twelve principal districts of England, amounts to between 4.408 and 1.645 times that of a tallow candle (6 to the pound), but ordinarily about 2 or 3 times, when the consumption varies from 2.3 to 1.5 cubic feet (per hour), and the specific gravity from 0.58 to 0.412.

With the same burner and gas, the amount of light depends upon the height of the flame, which practically, the pressure being nearly constant, is regulated by the position of the cock, or by varying the size of aperture in the burner. According to Christison and Turner, the advantage increases with the height of the flame, but to a limited extent only, and for a simple jet in the following proportion :—

Length of the flame in inches.	Intensity of the light from equal quantities of		Coal-gas.		Oil-gas.	
	Coal-gas.	Oil-gas.	Intensity of the light.	Gas consumed.	Intensity of the light.	Gas consumed.
1		100	—	—	22.0	33.1
2	100	122	55.6	60.5	63.7	78.5
3	109	159	100.0	101.4	96.5	90.0
4	131	181	150.0	126.3	141.0	118.0
5	150	174	197.8	143.7	178.0	153.0
6	150	—	247.4	182.2	—	—

Thus the point at which further advantage ceases to result on raising the flame of oil-gas is 4 inches, whilst for coal-gas it is 5 inches, which in general requires the flames to be higher. The consumption of gas and the intensity of the light increase together, but the latter in a more rapid ratio up to a certain point. This

occurs to a still greater extent with Argand burners, for which, with the same consumption of gas, these observers found the intensity of the light to be—

	100	282	560	582	582	504	
at a height of	½	1	2	3	4	5	inches.

According to Fyfe's experiments upon different burners, in which he probably used a better kind of coal-gas, the increase is as follows:—

Argand-burner.	With 24 apertures of $\frac{1}{40}$ of an inch, the diameter of the perforated ring being $\frac{7}{8}$ of an inch	—	100	121.8	—	188.5	—	236.6	235.4
	With 42 apertures of $\frac{1}{50}$ of an inch, the ring being $\frac{2}{10}$ of an inch in diameter . .	100	136.6	—	176.2	—	194.8	—	242.3
	Height in inches	1	1.5	1.75	2	2.5	2.75	3	3.5

With a bat's-wing he found the intensity of the light in the highest position of the flame to be 117, at a medium height 105, at its lowest point with the same consumption 100. Lastly, his experiments give a view of the intensity of the light produced by the same quantity of gas in different burners, when separately compared at the most advantageous height of the flame.

Burners.	Simple jet.	Bat's-wing.		Fish-tail burner.	Argand-burners.	
		Small.	Large.		With 24 holes.	With 42 holes.
Quantity of light from the same amount of gas.....	100	135	164	138	183.5	182.3

According to the observations of Hedley already quoted, which were made in the gas-works at Sheffield, the intensity of the light of a simple 4 inch jet is to that of a 3.5 inch Argand flame (from 14 apertures) as 1 : 4.4 to 4.8, the amounts consumed being as 1 : 3 cubic feet, which corresponds to a greater amount of light from the Argand burner by from 1.47 to 1.6 for the same quantity of gas. From the general report of the same engineer upon the principal gas-works in England, it is found (in the case of coal-gas), the average specific gravity being 0.476, that a simple jet, 4 inches in height, consumes on an average 1 cubic foot per hour.

The superiority of the flat flames over the simple (round) ones explains an observation which has been made with regard to the Argand burners. When the apertures in it are placed so far apart

as to form a circle of distinct jets, the effect is $\frac{1}{3}$ weaker (with the same current of gas) than when the jets (of $\frac{1}{6}$ to $\frac{1}{8}$ inch) unite into a single flat ring.

The following experiments on the illuminating power of Wigan cannel-gas with different burners have been recorded by Mr. Alfred King:—

	½ ft.	1 ft.	1½ ft.	2 ft.	2½ ft.	3 ft.	3½ ft.	4 ft.	4½ ft.	5 ft.	5½ ft.
Single Jet:—											
Consumption per hour	.5	1.	—	—	—	—	—	—	—	—	—
1 ft. = candles.....	2.15	2.6	—	—	—	—	—	—	—	—	—
1 ft. = grs. of sperm..	258.3	311.8	—	—	—	—	—	—	—	—	—
Lancashire Fish-tail No. 0:—											
Consumption per hour	.5	1.	1.5	—	—	—	—	—	—	—	—
1 ft. = candles.....	1.78	2.18	1.76	—	—	—	—	—	—	—	—
1 ft. = grs. of sperm..	214.1	262.5	211.9	—	—	—	—	—	—	—	—
Lancashire Fish-tail No. 1:—											
Consumption per hour	.5	1.	1.5	2.	—	—	—	—	—	—	—
1 ft. = candles.....	1.76	2.65	2·55	2.53	—	—	—	—	—	—	—
1 ft. = grs. of sperm..	211.3	317.9	306.5	303.7	—	—	—	—	—	—	—
Lancashire Fish-tail No. 2:—											
Consumption per hour	.5	1.	1.5	2.	2.5	3.	—	—	—	—	—
1 ft. = candles.....	2.26	3.11	3.5	3.79	3.79	3.66	—	—	—	—	—
1 ft. = grs. of sperm..	271.2	373.3	420.6	455.7	455.7	439.4	—	—	—	—	—
Lancashire Fish-tail No. 3:—											
Consumption per hour	.5	1.	1.5	2.	2.5	3.	3.5	—	—	—	—
1 ft. = candles.....	2.26	3.48	3.86	4.07	4.07	4.18	4.1	—	—	—	—
1 ft. = grs. of sperm..	271.2	417.4	463.6	488.3	488.3	501.9	492.8	—	—	—	—
Lancashire Fish-tail No. 4:—											
Consumption per hour	.5	1.	1.5	2.	2.5	3.	3.5	4.	—	—	—
1 ft. = candles.....	2.38	3.49	4.00	4.17	4.74	4.5	4.41	4.3	—	—	—
1 ft. = grs. of sperm..	285.5	419.5	484.4	500.5	566.7	539.9	530.1	516.6	—	—	—
Bat's-wing:—											
Consumption per hour	.5	1.	1.5	2.	2.5	3.	3.5	4.	4.5	5.	—
1 ft. = candles.....	1.83	3.01	3.73	4.1	4.12	4.31	4.3	4.46	4.32	4.4	—
1 ft. = grs. of sperm..	220.	361.6	448.3	492.3	494.8	578.1	516.2	535.1	519.	528.9	—
Sixteen-hole Argand, small holes in ring, 0·32 in diameter:—											
Consumption per hour	—	1.	1.5	2.	2.5	3.	3.5	4.	4.5	—	—
1 ft. = candles.....	—	0.323	1.02	1.9	2.6	3.27	3.72	3.84	3.96	—	—
1 ft. = grs. of sperm..	—	38.76	123.3	228.7	313.	393.3	446.4	461.7	479.2	—	—
Winfield's Twenty-eight hole Argand, registered July 25, 1848, with slightly conical Chimney:—											
Consumption per hour	—	1.	1.5	2.	2.5	3.	3.5	4.	4.5	—	—
1 ft. = candles.....	—	0.344	1.16	2.26	2.71	3.5	3.72	3.84	4.	—	—
1 ft. = grs. of sperm..	—	41.3	139.1	271.3	325.6	420.5	446.4	461.7	481.	—	—
Winfield's Fifty-eight hole Lucent Argand, registered March 20, 1845:—											
Consumption per hour	—	—	1.5	2.	2.5	3.	3.5	4.	4.5	5.	5.5
1 ft. = candles.....	—	—	0.318	0.73	1.09	1.57	2.09	2.59	3.07	3.82	4.5
1 ft. = grs. of sperm..	—	—	38.2	87.5	131.8	188.4	251.1	311.3	368.9	458.8	540.

The following experiments upon the illuminating power of Newcastle cannel-gas were made by Mr. Wright with the burners used in London for consuming that kind of gas:—

The No. 1 Scotch fish-tail burner gives a flame fully spread with .85 inch pressure, and when burning at the rate of 1.4 feet per hour, beyond which point it begins to show streaks of blue.

The No. 2 Scotch fish-tail is fully spread with .9 inch pressure, and when burning at the rate of 2.4 feet per hour.

Guise's burner is an Argand with twenty-six holes, the inner diameter of the ring being six-tenth inch, and the outer nine-tenth inch. It has a metal button, five-tenth inch diameter, one inch above the face of the burner. The glass chimney is a straight cylinder, 2 inches diameter and 6 inches long.

With three-tenth inch pressure, and a consumption of 4.5 feet per hour, the flame becomes irregular, and has a tendency to deliver smoke.

The standard candle used by Mr. Wright consumed 130 grains per hour, and for this, to ensure a greater regularity of flame, a No. 2 fish-tail, burning .4 feet per hour, was substituted, and found exactly equal to the candle.

In the first of the following tables the results are multiplied by 130 and divided by 120, so as to reduce them to a standard candle of 120 grains per hour, as done by Mr. King.

Consumption per hour.	½ ft.	1½ ft.	2 ft.	2½ ft.	3 ft.	3½ ft.	4 ft.	4½ ft.
Scotch Fish-tail No. 1:—								
1 foot = candles	4·875	5.02	—	—	—	—	—	—
1 foot = grains of sperm	585.	602.	—	—	—	—	—	—
Scotch Fish-tail No. 2:—								
1 foot = candles	5.05	5.77	5.95	5.84	5.53	—	—	—
1 foot = grains of sperm	606.	690.	714.	700.	663.	—	—	—
Guise's Argand:—								
1 foot = candles	—	1.08	1.85	3.12	4.85	4.95	5.77	6.74
1 foot = grains of sperm	—	129.	222.	374.	582.	594.	692.	808.*

Mr. Wright, however, prefers the following form of quoting the above results:—

SPERMACETI CANDLES OF 130 GRAINS PER HOUR.

No. 1 Scotch Fish-tail:—												
Gives light = ...	½	¼	⅛	1	2	4	6	8	candles.			
When burning	.15	.2	.3	.4	.6	.9	1.3	1.8	feet per hour.			
Feet of gas required to produce a light = one candle	1.2	.8	.6	.4	.3	.225	.217	.225				
No. 2 Scotch Fish-tail:—												[dles.
Gives light = ...	½	¼	⅛	1	2	4	6	8	10	12	14	16 can-
When burning	.15	.2	.3	.4	.6	.9	1.2	1.5	1.8	2.2	2.6	3.2 feet per
Feet of gas required to produce a light = one candle	1.2	.8	.6	.4	.3	.325	.2	.1875	.18	.183	.185	hour. .2
Guise's Argand.												
Gives light = ...	2	4	8	12	16	20	24	28	candles.			
When burning	1.7	2.1	2.6	3.1	3.5	3.9	4.2	4.5	feet per hour.			
Feet of gas required to produce a light = one candle	.85	.525	.325	.258	.219	.195	.175	.160				

Mr. Barlow has recorded some experiments* made by him with different burners, on gas manufactured from a mixture of Pelton, Felling and Dean's Primrose, all first-class Newcastle gas coals, the average produce being 8500 feet per ton of coal. The burners he used were—

1st. A No. 3 fish-tail, or union jet.

2nd. A No. 5 batswing.

3rd. A common argand, with fifteen large holes in a ring .85 in. diameter, and a cylindrical chimney-glass 7 in. high.

4th. A Platow's registered (Nov. 2, 1840) argand, with sixteen large holes in a ring ·9 in. diameter, with inside and outside cone, and cylindrical chimney-glass 8.5 in. high.

5th. A Bynner's patent No. 3 argand, with twenty-eight medium-sized holes in a ring .75 in. diameter, and cylindrical chimney-glass 8.65 in. high.

†6th. A Winfield's registered (March 20, 1845) argand, with fifty-eight medium-sized holes in two rings of twenty-nine holes in each, the mean diameter being 1 inch, with deflecting button inside, and gauze below; bellied chimney-glass 8 in. high.

7th. A Leslie's patent argand, with twenty-eight jets in a ring .95 in. diameter, and chimney-glass 3.5 in. high.

8th. A Guise's registered (May 2, 1849) shadowless argand, with twenty-six large holes in a ring .85 diameter, and deflecting button; cylindrical chimney-glass 6.1 high, and glass reflecting-cone to outside gallery.

* Journal of Gas-lighting. June, 1851.

† This is the burner used by Dr. Fyfe in his experiment, and called by him the Aberdeen argand.

On an average of numerous trials the following results were obtained :—

SERIES No. 1.

Burner.	Consumption per hour.	Value of 1 cubic foot in grains of sperm.	Standard candles per cubic foot.	Value of 8500 feet of gas in lbs. of sperm.
No. 2.	4.9	289.	2.4	351.
No. 3.	5.5	343.	2.85	416.
No. 5.	5.5	374.	3.11	447.
No. 6.	5.5	337.	2.8	409.
No. 8.	5.5	350.	2.91	425.

SERIES No. 2.

No. 1.	5.5	276.	2.3	335.
No. 2.	5.0	290.	2.41	352.
No. 3.	5.5	341.	2.84	414.
No. 4.	5.5	348.	2.9	422.
No. 5.	5.5	380.	3.16	461.
No. 6.	5.5	335.	2.79	406.
No. 7.	4.1	369.	3.07	448.
No. 8.	5.5	364.	3.03	442.

It is quite evident from these experiments that the No. 6, or Dr. Fyfe's Aberdeen argand, required a larger consumpt than 5.5 feet per hour to bring out the full effect of Newcastle coal gas of the quality used in this case, for when the consumpt was increased to 6.5 feet per hour, it gave results equal to any of its compeers, at 5.5 feet. No. 2 and No. 7 burners were tried with the utmost quantity which could be consumed in them without smoking or burning disadvantageously.

Though these experiments indicate the relative adaptation of the several burners for the combustion of Newcastle coal gas, they must not be taken as settling the question of the practical value of each. Some of them cast shadows which detract considerably from the light they yield when placed above the level of the eye; this is particularly the case with No. 5, which otherwise gives the best results. Others, like No. 7, require a perfect uniformity of pressure, and an absence of all currents of air. Taking all things into consideration, No. 8 is, perhaps, the one to which these objections least apply, and it gives the next largest amount of light for the gas consumed, though the slight advance upon the old argand, as constructed twenty-five years since, cannot fail to be remarked.

Glass chimneys are not so requisite for gas- as for lamp-flames, and their effect is quite different from that exerted upon the wick

flame of a lamp. The jet of gas, as it leaves the burner, is in far more correct relation to the air than is the case with the gas produced at the burning margin of the wick.

Argand wick-flames require a strong draught, and never burn without smoke unless a chimney is used; with gas-flames, the glasses are used rather to steady the flame than to ensure its perfect combustion: they are always made shorter than the glasses of oil-lamps. If too high chimneys are used, the draught of air soon cools the base of the flame, and the air becoming mixed with the gas, a diminution of the light results, which is caused by the combustion of too much carbon simultaneously with the hydrogen; hence but little is momentarily separated in the flame. A striking proof of this is afforded by the well-known experiment in which a closed cylinder of wire-gauze, through which flame cannot be communicated to a combustible mixture, is adapted to a gas-burner. The jet of gas, which without the case of wire-gauze yields a perfect flame, becomes intimately mixed with air in the interior of the case, and on its exit burns with a pale blue light, because the separation of carbon in the flame no longer occurs, both carbon and hydrogen being burned simultaneously. This experiment gives an important hint on the general management of the draught in illumination. The same result may be observed when the gas is allowed to escape with too great velocity; and, if the proper limit is exceeded, the flame may be extinguished by being too much cooled: with a certain velocity, the current will not ignite for a distance of several lines from the aperture, and then burns with a faint blue flame, the gas having become mixed with air.

It is by taking advantage of this effect of a strong current of air that the highly carbonaceous vapours of oil of turpentine, coal-tar, naphtha, and similar substances, may be burned without smoke, as in Busson and Rouen's apparatus, or in Holliday's lamps. The oils being allowed to escape in the form of a jet of vapour, under a pressure varying, according to circumstances, from 4 to 24 lines of mercury, the excess of carbon is brought to a proper proportion by the admixture of air, without interference with the order of combustion. In this manner brilliant flames, free from soot, are produced.

Comparison of the various Methods of Illumination with each other.—In the foregoing remarks, the relative illuminating values of the various methods of producing artificial light have generally been shown, without reference to the cost of the light. This still

remains to be done, in order to establish their relative economy. In the following sketch (by Peclet) the cost has in each case been taken into account; but this will vary with the rise and fall of markets, and with the locality. The price of a pint of oil (0.9 lb.) is here fixed at about 5d.; of 1 lb. of tallow candles at 7d., wax candles at 2s. 2d., stearine candles at 1s. 4d.; a pint of illuminating spirit (0.8 lb.) at 8d.; of 100 cubic feet of coal-gas at 7d.; and lastly, of 100 cubic feet of oil-gas at 2s. 8d.

Means of illumination.	Intensity of the light.	Consumption of illuminating material per hour.	Illuminating power, Carcel's lamp = 100.	Price of 100 grammes of illuminating matters.	Cost of the light per hour in pence.	Cost of a light of the same intensity per hour in pence.
Tallow candles, 6 to lb.	10.66	8.5	54.04	1.5	0.125	1.169
Wax „ 6 „	14.60	9.6	61.57	5	0.461	3.155
Stearine „ 5 „	14.40	9.3	66.58	3.2	0.298	2.066
Kitchen-lamp	6.65	8.0	33.60	1.4	0.083	1.246
Lamp with flat wick	12.50	11.0	47.50		0.114	0.912
Astral-lamp	31.00	26.7	48.70		0.280	0.893
Sinumbra-lamp	56.00	37.1	63.0		0.385	0.687
Lamp with inverted reservoir	90.00	43.0	87.8		0.446	0.495
Hydrostatic-lamp	45.00	17.26	109.2		0.179	0.398
Carcel's lamp	100.00	42.0	100.0		0.435	0.435
Vapour-lamp	130.70	151.0 C. F.	36.2	1.3 per 100 C. F.	2.013	1.207
Coal-gas	127.00	8.70	—	7.0	0.580	0.456
Oil-gas	127.00	2.43	—	19.2	0.630	0.367

The light of wax candles is the most expensive; then that of stearine candles and the vapour-lamp, which are also costly. There are, however, few instances where public opinion and scientific estimation of the value of an article are so much at variance as is the case with the means of illumination in general, occasional deceptions, such as occur in Benkler's lamp, not being taken into consideration. A glance at the last column in the table shows that the modes of illumination which, on account of their supposed cheapness, are partly used by the wealthy and exclusively by the poor, are those which (excluding articles of luxury, such as wax, &c.) cost most in producing a certain degree of brilliancy. A given amount of light yielded by tallow candles costs from three-fifths to twice as much as when it is obtained from Carcel's lamp; with the kitchen lamp it costs nearly three times, and by the lamp with the flat wick more than twice as much.

The more ordinary light-giving materials have recently been examined by Mr. L. Thompson, and compared with the light obtained from what is called common or 13-candle coal-gas. Tried by the photometer,—

1000 cubic feet of gas were found to equal the light of	312,000	grains or	44⅔ lbs. of sperm candles.
Ditto	341,750	,,	48⅞ lbs. of carefully snuffed wax candles.
Ditto	358,000	,,	51⅛ lbs. of stearic acid candles.
Ditto	370,540	,,	52 9/10 lbs. of best mould candles.
Ditto	381,000	,,	54⅜ lbs. of best dip candles.
Ditto	417,220	,,	6½ gallons of purified colza oil, sp. gr. 915.
Ditto	366,310	,,	5 9/10 gallons of sperm oil, sp. gr. 888.

As the price of gas varies in different parts of the United Kingdom from 4s. 6d. to 10s. per 1000 cubic feet, to obtain the relative cost it is necessary to multiply the prices of the other materials per lb. with the numbers in the above table.

Thus, gas at 4s. 6d. per 1000 cubic feet, and dip candles at 7d. per lb., the cost of an equal amount of light from the two sources will be as 4s. 6d. to £1. 10s. 10d.

The great obstacles to the more general introduction of gas-light into private houses are the difficulty of placing the light in such a position as to be available for all purposes, and in reducing the consumption to the requirements of the consumer. A candle or a lamp can be placed wherever it is wanted, while a gas-light, even when flexible india-rubber tubes are used, is always more or less a fixture. The burners in common use are also calculated for giving more light than is required for one or two persons, and hence, though the light from gas is so very much cheaper, yet a larger quantity of light than is absolutely necessary being generally employed wherever gas is introduced, the actual saving by its introduction is not so great as the difference of price in the light would make it appear.

The foregoing tables also show that the most economical light is obtained from the best-constructed lamps, which, in addition to being costly themselves, also consume large quantities of oil, and are therefore not economical when used by a single person. There still appears much room for improvement in the adaptation of good lamps to the requirements of small consumers. A lamp which would give the light of one or two spermaceti candles, and yet be relatively as economical in the consumption of oil as Carcel's or the French moderator lamp, would probably command an extensive sale.

Application of Gas as a Source of Heat.—Gas has long been employed as a source of heat in chemical and pharmaceutical laboratories, but it is only during the last few years that it has been more extensively used for cooking, and warming apartments. Under certain circumstances, gas may be a more economical fuel than coal: where heat is required quickly, and only for a short time, the waste which necessarily accompanies the lighting of a coal fire is far more than equivalent to the higher cost of the gas, which in large towns can be obtained at any moment, and, with proper contrivances, in the precise quantity required. It is estimated that for the four or five months in the year when a fire is not required for heating the kitchen, it is more economical to cook by gas in London than by a coal fire. With reference to the amount of water converted into steam by gas in ordinary burners, Mr. Evans has obtained the following experimental results :—

One cubic foot of gas, weighing about 205 grains, and of specific gravity 0.413, boiled off $\frac{4}{10}$ths of a lb. of water, or 13.6 times its weight.

One cubic foot of gas, weighing about 290 grains, and of specific gravity 0.564, boiled off $\frac{5}{10}$ths of a lb. of water, or 12 times its weight.

One cubic foot of gas, weighing about 360 grains, and of specific gravity 0.700, boiled off $\frac{7}{10}$ths of a lb. of water, or 13.6 times its weight.

Theoretically, Newcastle coal gas, of specific gravity 0.416, has an evaporative value equal to about 22 times its weight; or in other words 1 lb. of such gas should convert 22 lbs. of water into steam: there is hence a loss of one-third at least of the heat evolved when the gas is consumed in the ordinary manner. Mr. Defries has economised the heat to a great extent in his application of gas to the heating of baths; with 30 cubic feet of gas he heats 45 gallons, or 450 lbs. of water, from 50° F. to 100° F., and at a cost of only three-halfpence. This is equal to 15 lbs. similarly heated for each cubic foot of gas, weighing say 206 grains, or 750 lbs. of water heated 1 degree by the same means. Estimating the latent heat of steam at 960, this gives 25 parts of water boiled off for every 1 part of gas consumed, which is very nearly three times as great as the heating power of Newcastle coal.

Mr. Lewis Thompson finds that a gallon of water may be more economically brought to the boiling point by a gas stove, than by

a recently lighted coal fire. The relative cost of the two methods being as under:

	Coal used.	Wood used.	Time employed.	Total cost.
With fire	4½ lbs.	⅛ of 1d.	1 hour	$\frac{17}{100}$ of 1d.
With gas	4 cubic feet of gas at 4s. 6d. per 1000.		20 minutes	$\frac{22}{100}$ of 1d.

There is therefore according to this estimate an economy in price of nearly 3 per cent, and a saving in time of two-thirds, besides great cleanliness and comfort in the use of gas.

Gas stoves and ovens for culinary purposes are now made in a great variety of forms: the arrangements for boiling consist generally of large ring-shaped burners. The ovens are of sheet iron, below which the gas is burnt, while the hot gases from the combustion circulate round the sides.

Gas stoves for heating the air of rooms offer no remarkable features of novelty, the gas-burners simply taking the place of the fuel in ordinary stoves: the air currents must be regulated in accordance with the principles laid down in a former chapter, in order to obtain the full value of the combustible: sheet iron is the material generally employed for collecting and distributing the heat. In the proper consumption of gas for heating rooms, no smoke is evolved, and gas stoves have consequently often been constructed without any flue for carrying away the products of combustion, and the air of the apartments then becomes rapidly impregnated with carbonic acid gas, which is the more dangerous as the absence of smoke masks the presence of the poison.

The sight of a fire being indispensable to an Englishman's idea of comfort, inventors have endeavoured to imitate the combustion of solid fuel by causing a number of small gas jets to heat solid bodies to a high temperature, and thus produce the semblance of an ordinary coal fire. Among the ingenious contrivances for this purpose, those of Mr. Goddard, of Ipswich, may be introduced as an illustration. Fig. 407 represents a portable gas fireplace, which may be placed on the hearth of a room from which the ordinary grate has been removed. The lid of the moveable box opens in the centre, and the two pieces form the sides of the grate shown in Fig. 408, with its flattened coil of perforated bars, which form the burner, exposed. Fig. 409 shows an incollapsable grate with the appearance presented when the jets of gas are ignited, and shavings of asbestos strewn over them: these become incandescent by the heat, and present the appearance of fuel.

A fire of this kind for an ordinary room is estimated to consume about 7 feet of gas per hour, costing about 4d. for 12 hours. The asbestos being incombustible lasts for a great length of time, and sufficient can be obtained for 6d. for covering the bars. Various sized pieces of common peroxide of manganese, pumice-stone, and fire-brick, have been substituted by some for the asbestos, and metallic platinum has recently been patented for this purpose by Backhofner and Defries, to produce what has been termed the polytechnic fire. This, though costly at first, is quite indestructible, and as far as appearance and comfort are concerned is said to be most successful. By placing these gas grates under a chimney flue, perfect ventilation is secured. Although these inventions are limited at present to large towns where gas is comparatively cheap, and the pressure at the gas-holder is maintained during the day-time, yet it appears probable that its use as a calorific agent will extend as it becomes more universally employed, and consequently cheaper. The extra cost of the gas is even now counterbalanced by the saving of labour, the absence of smoke, soot, and ashes, with the expenses attending their removal.

FIG. 407.

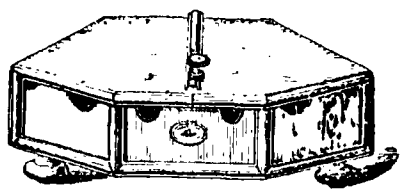


FIG. 408.

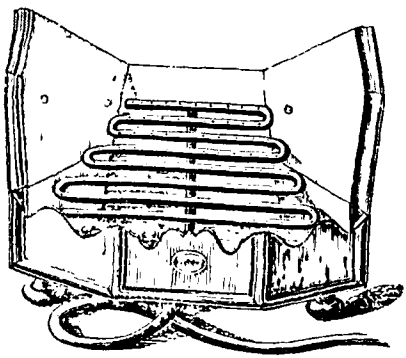
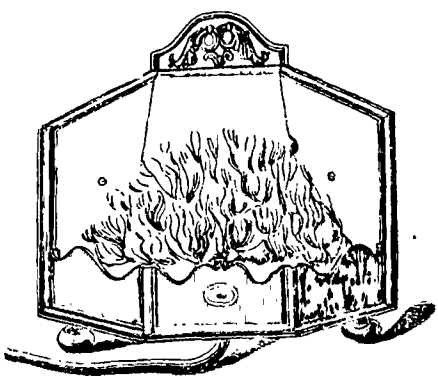


FIG. 409.



SECONDARY PRODUCTS OF THE GAS MANUFACTURE.

The table by Mr. Wright, at page 577, shows the relative proportion of coke, gas, tar, and ammoniacal water afforded by a ton of some of the cannel coals employed in gas making; and another table, in the section, "What is coal," a few pages further on, gives additional information on this point. The quantities of these products from 1 ton vary within certain limits with the different kinds of coal, and with the mode of conducting the distillation, but as a general average the following quantities may be taken as the product of good Newcastle coal:—

1 chaldron of coke . . .	1,494 lbs.
12 gallons of tar	135 „
10 „ ammoniacal liquor .	100 „
9500 cubic feet of gas . . .	291 „
Loss	220 „
	2,240 lbs.

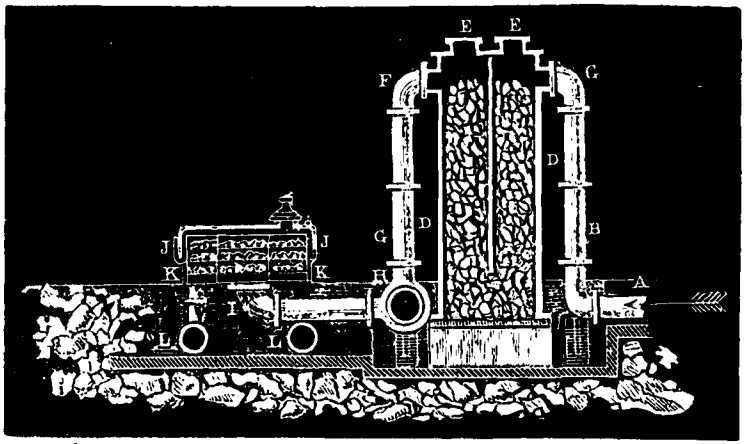
Preparation of Ammonia and its Salts from Gas-water.—The salts of ammonia evolved in the distillation of coal are contained for the greater part in the water or condensed ammoniacal liquor; portions however pass on with the gas, and special means have been devised, as described under the purifying processes, to separate and convert them into a commercial shape. A modification of the breeze condenser shown in Fig. 410, is sometimes used for separating portions of ammonia and tar which have escaped condensation in the usual condensers. It consists of a large metal cylinder D, divided into two compartments by a diaphragm. E E are two large man-hole doors, through which to fill in the coke. The arrow indicates the course of the gas from the condensers, which passes to the top of the cylinder by the pipes B C, descends on one side and ascends on the other, through the coke, leaving the tar behind, and ultimately passing through F G to a common pipe H, is distributed to the various lime purifiers J K.

This mechanical purification of the gas much facilitates its chemical treatment afterwards, and the coke, which lasts for about six weeks in winter, yields its ammonia, and finally may be used for fuel.

The ammoniacal water floats on the surface of the tar in the tanks prepared for its reception, and consists of a solution of various

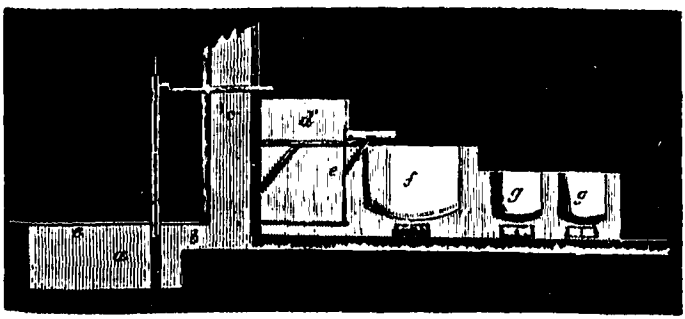
salts of ammonia, chiefly the muriate and carbonate, with sulphide and cyanide of ammonium, and probably numerous other sub-

FIG. 410.



stances of a basic character, and nearly allied to ammonia. Several of the compound ammonias have lately been found in coal-tar naphtha, and some of the more volatile of the series will no doubt be found in the ammoniacal liquor. These are constituted like

FIG. 411.



ammonia, but differ from it in having one or more of the hydrogen elements replaced by organic basyles,—as methyl, ethyl, &c.

Thus Ammonia is NH_3 Ethylamine $N\left\{\begin{matrix}H_2\\C_4H_5\end{matrix}\right\}$

Methylamine $N\left\{\begin{matrix}H_2\\C_2H_3\end{matrix}\right\}$ Biethylamine $N\left\{\begin{matrix}H\\2(C_4H_5)\end{matrix}\right\}$

This liquor, or gas water, since the use of coal gas has become so general, has been employed as the chief source of the salts of ammonia, and also of the alkali itself, which is extensively used in dyeing.

Ammonia is sometimes obtained from soot by the distillation of resin, bones, and other animal matters. Patents have also been secured by Young, Turner, Hills, and others, for obtaining ammonia from guano, peat, schist, &c., a very useful summary of which will be found in the 13th volume of the "Pharmaceutical Journal."

Sulphate and Muriate of Ammonia.—The crude gas water is easily separated by pumps from the tar on which it floats, and is saturated either by muriatic or sulphuric acid in close tanks, whence the sulphuretted hydrogen and other gases discharged are carried off by flues into some main chimney. An arrangement for effecting this is shown in Fig. 411, where *a* represents the underground tank for mixing the gas-water and acid, the large flue *b* being intended to carry off the escaping gases to the chimney *c*. Another plan consists in collecting the gas-water in the tank *d* and allowing it to flow through a perforated pipe *e* into the underground tank *a*, where it meets a stream of muriatic acid, produced by decomposing common salt with sulphuric acid. The liquor, after standing, is then run into a large pan *f*, where it is brought up to the boiling point to separate the tarry matters as much as possible. The purified liquor is then syphoned off into the smaller pans *g g*, where it is concentrated by evaporating to the point of crystallisation.

In other manufactories, the liquid is pumped into large cisterns on the top of coke columns, down which a stream is allowed slowly to fall, where it meets a current of sulphurous acid gas, or the waste gases escaping from a sulphuric gas chamber in its descent. The liquor thus neutralised furnishes sulphate of ammonia when boiled. Messrs. Hills, the Bonnington Chemical Company, and other manufacturers, employ large boilers, where the gas-water is heated with some lime to expel the ammonia; the gas evolved is brought into contact with sulphuric acid, so as to form a strong solution of sulphate of ammonia, and save much of the expense now attending the boiling down of weak ammoniacal solutions. In Messrs. Hills' works the volatile ammonia, instead of being conveyed directly to the oil of vitriol, is passed into a coke column,

where it condenses with the steam which has accompanied it, and falling down, meets a current of steam so regulated as to volatilise the ammonia, while it is itself condensed by the water which had held the ammonia in solution. Two objects are accomplished by this elegant arrangement: the colouring matter is more perfectly separated, and by passing the gas through vitriol crystallised sulphate of ammonia is formed in one operation.

At Bonnington, the worm conveying the vapours from the large ammonia stills is carried through a closed metal tank containing ammoniacal liquor. The vapours are condensed by this liquor, which thus becomes heated, and evolves a considerable part of its gaseous ammonia, principally in the form of carbonate, which is conducted into a vessel containing strong vitriol: the liquid in the tank having become heated, is transferred to the still, and its place supplied by a fresh charge of crude ammoniacal water.

About one-eighth of the bulk of the crude gas liquor is distilled over, and a gallon of the product yields from 31 to 39 ounces of crude sal-ammoniac, or a proportionate quantity of crude sulphate.

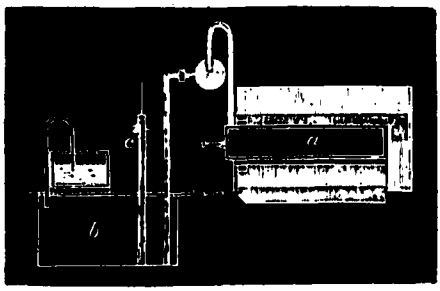
Mr. Spence, of Pendleton, employs a range of cylindrical boilers so placed that the liquor may be drawn off from any one to that below it. High-pressure steam being admitted into the lowest boiler, the ammonia and vapour pass off into the higher, and so on through the series, until they escape from the last in so concentrated a form, that on passing through sulphuric or muriatic acid the solution becomes so concentrated as to dispense with all evaporation.

Fresh gas-water is run into the highest boiler as the weaker liquor is drawn off to the one below, and this is continued until the exhausted liquor may be discharged from the lowest boiler in the range.

When the liquor is simply neutralised by sulphuric or muriatic acid, and boiled down to strength (50° Twaddle for muriate), a quantity of tar accumulates on the surface, which must be removed from time to time, as it seriously impedes the evaporation. In certain manufactories this purified liquor is employed directly in the manufacture of alum, or of Richardson's double sulphate of ammonia and magnesia. Numerous patents have been secured for preparing the sulphate and muriate of ammonia directly during the manufacture of coal-gas, which have been already alluded to at pages 610 to 614.

In the preparation of animal charcoal, as shown in Fig. 412, where bones are distilled in a common gas retort *a*, and the liquid products collected in an underground tank *b*, there is an ammoniacal liquid produced which is pumped off at *c*, and treated in the manner already described. In France, where much ammoniacal salt is obtained from this source, the liquor is filtered, and either neutralised with hydrochloric acid, when the dried chloride is sublimed in earthen pots placed in a kind of gallery furnace, or the crude liquor is passed several times through a bed or filter of gypsum, which converts it partially into sulphate. The solution thus obtained always requires a little additional acid to render it neutral, and is much contaminated with animal impurities. Much of the ammonia is also lost by evaporation during the process. The sulphate is decomposed with common salt when required to be converted into muriate, and treated as described below.

FIG. 412.



The sublimed chloride, even when perfectly white, sometimes contains protochloride of iron, which is made apparent by converting the proto- into perchloride by nitric acid, and then testing with ferrocyanide or sulphocyanide of potassium. Brewer proposes to remove this from the crude salt by passing a very little chlorine gas through a saturated boiling solution, and subsequently adding ammonia: the protosalt is thus converted into persalt, and the peroxide precipitated by the ammonia.

In 1850 Michiel obtained a patent for preparing sulphate of ammonia by treating gas-water with an oxysulphate of lead, prepared by roasting ground galena in a reverberatory furnace, where the ore is converted into a mixture of oxide and sulphate. The resulting compounds are sulphide and carbonate of lead and sulphate of ammonia.

Wilson carries the vapours from coke-ovens through dilute sulphuric acid contained in a cistern, over which a coke column is erected, and through which the vapours are passed after leaving the acid solution, and meet in their ascent a shower of dilute acid from a cistern at the top of the column with a perforated bottom.

All the ammoniacal vapours are thus extracted and converted into sulphate of ammonia.

Muriate of Ammonia—Sal-ammoniac.—Where the object is to produce sal-ammoniac, and muriatic acid is too costly to be employed directly in neutralising the gas-water, the purified liquor containing sulphate of ammonia is mixed with its equivalent quantity of common salt. During the subsequent evaporation, the sulphate of soda separates in hard granular crystals, which are very apt to adhere to the sides of the boiler. The liquor is agitated to prevent this adhesion taking place, and assist in the separation of the sulphate of soda. The double decomposition of common salt and sulphate of ammonia is thus represented:—

$$N\,H_4O,\,SO_3 + Cl\,Na = N\,H_4,\,Cl + NaO,\,SO_3\,HO.$$

The evaporation is best conducted in shallow wooden cisterns, lined with lead, heat being applied by a coil of steam pipe. This arrangement permits the workmen to remove the sulphate of soda as it is formed into drainers so arranged that the adhering muriate of ammonia may fall back into the boiler. The mother liquor is boiled up to the crystallising point (sp. gr. 1.25), and run off into coolers. The crystals of impure muriate of ammonia subside in from four to six days, and are coloured more or less by the tarry matters; they must be perfectly dried on properly constructed hearths or ovens before they can be used in making sal-ammoniac.

In other localities, the mother liquor from sea salt, *bittern*, and the waste muriate of manganese from the bleaching-powder process, have been employed to produce the muriate of ammonia, as the following formula illustrates:—

$$\left\{\begin{array}{l} NH_4S,\,HS + NH_4O,\,2\,CO_2 + 2\,Mn\,Cl = \\ 2\,NH_4Cl + MnS + HS + MnO,\,CO_2 + CO_2. \end{array}\right.$$

When bittern is used, the resulting carbonate of magnesia may also be obtained, and this process is practised at Glasgow—

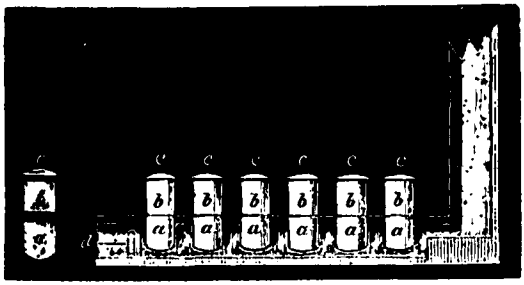
$$NH_4O,\,2\,CO_2 + MgCl = NH_4Cl + MgO,\,CO_2 + CO_2.$$

The carbonate of magnesia settles down, and the muriate of ammonia may be drawn off and evaporated.

It is an important point in the production of sal-ammoniac, that the rough muriate of ammonia should be perfectly dried to prevent loss during the subliming process, and avoid the risk of explosions. It is also desirable to prevent the formation of large crystals in the first crystallisation, the small crystals being purer, and more easily dried and sublimed. The finely powdered dry muriate of ammonia is mixed with a little animal or vegetable charcoal, which, by acting upon the

chloride of iron, prevents the sublimate being yellow coloured. The charge is well beaten down in the metal pots *aaa*, Fig. 413, to which the leaden domes or covers *bbb* and *ccc* are afterwards attached. Each pot is heated by a separate fire, or the whole range by one as shown at *d*. The pots are filled to within four or five inches of the top, and when the steam begins to be rapidly evolved, the domes or caps are attached and well luted by a mixture of clay and charcoal. A small hole at the top of *c* is kept open by a bore rod to allow the remainder of the steam to escape, and great attention to the regulation of the heat is necessary at this stage of the process to prevent the whole being blown up, or too much sal-ammoniac being carried off with the steam. After all the steam has escaped, there is still danger of an explosion should the dome become too hot, while, if the temperature be too low, the cake is apt to be soft and of a yellow colour.

FIG. 413.



Another mode of subliming sal-ammoniac, and which is generally adopted in this country, consists in employing much larger pots, with the dome in one piece, as shown in Figs. 414 and 415. The body *aa*

FIG. 414.

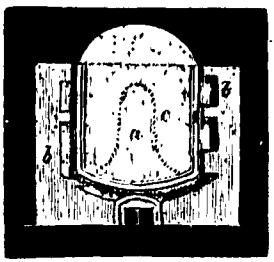
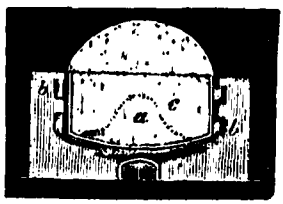


FIG. 415.



of the subliming vessel is of cast-iron, and heated from below and by flues *bb* round the sides. The same precautions are necessary in this case, but the whole of the muriate of ammonia cannot be sublimed, a mass called the yoke remaining in the pot *a*, of the shape shown by the dotted lines *cc*. This, as well as the cement

used for luting on the dome, is worked up with the fresh charges. The formation of the yoke has sometimes been obviated by making an artificial brick case of the same form and dimensions. In drying the crude sal-ammoniac before introducing it into the subliming pots, there is a loss of nearly 25 per cent, which is volatilised; and in the process of sublimation, which continues during an entire week of six days, there is an additional loss of about 11½ per cent on the dried muriate. The dome of the pots being removed by a crane, the cake which is attached is carefully removed. This cake is from 3 to 5 inches in thickness, and should be quite colourless, and uniformly tough throughout,—not brittle or soft,—and then requires only a little scraping, where it was in contact with the dome, to render it fit for the market. In Liverpool the domes employed are constructed of iron, but there is then more danger of the cakes being coloured.

Calvert has proposed and described the following process as an improvement upon the ordinary method of manufacturing sal-ammoniac:—

"The apparatus consists of a furnace the construction of which is very similar to that used in gas-works for heating retorts, in which are placed three or five clay cylinders, of 6 feet long, and from 15 to 18 inches in diameter at the end which is employed for charging, and which are gradually tapered, so that the other ends of the cylinders are only 8 inches in diameter. The large end of each cylinder is so placed that it just protrudes from the outer wall of the furnace, and is closed with a door similar to that used on gas-retorts, but with this difference, that the inside is lined with a layer of Kean's patent alum-plaster, while in the middle of this door there is an opening of about an inch and a half diameter, which enables the operator not only to judge how the operation is progressing, but also to establish a gentle draught through the retort to facilitate the passage of the vapours of sal-ammoniac from the cylinder to the condensing chambers. The smaller end of the cylinder penetrates through an opening made in the partition-wall which separates these chambers from the furnace. The condensing part of the apparatus is composed of three large chambers, built of bricks, and lined with silicious slabs as free from compounds of iron as possible. The dimensions of these chambers are as follows: the first chamber is 20 feet long, 12 feet broad, and 12 feet high; the second, 15 feet long, 10 feet broad, and 10 feet high; the third, 10 feet long, 8 feet broad, and 10 feet

high; the last chamber is provided with a small opening at its upper part, so as to enable a part of the air contained in it to escape when expanded by heat or driven away by the vapours of sal-ammoniac. Each chamber is provided also with a side-door for admitting men from time to time to remove the sal-ammoniac which has been condensed in it. These chambers are placed end to end, and are separated by partition walls, and the only communication between them is an opening of 2 feet square at the bottom of the first chamber, and a similar one at the top of the second. I should here remark that it is advisable to keep the apparatus almost constantly at work, and not to introduce into the cylinders too large a charge of well-dried ordinary commercial hydrochlorate of ammonia; a wet mass would not only split the red-hot retorts, but would also have the serious evil of giving rise to condensed water in the chambers, which would spoil the appearance of the sublimed sal-ammoniac, which should be perfectly white, and have a feathery crystalline structure when prepared by my process. I have not had occasion to try practically the following plan, but I am led to believe that it would prove advantageous. It would be, namely, to coat with Kean's patent plaster the stone slabs which line the inside of the chambers.

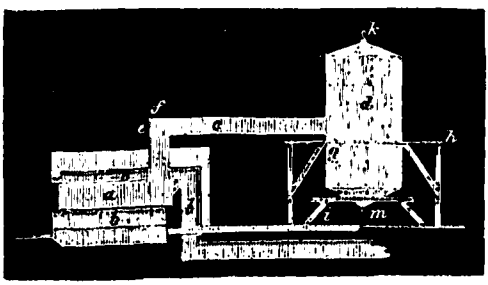
"It was after long and tedious trials that I discovered the method of preventing the chloride of iron, or more probably the double chloride of iron and ammonium, from subliming. The method consists in mixing intimately 5 per cent of dry biphosphate of lime with the dry hydrochlorate of ammonia, and then submitting the whole to sublimation, or what answers better, is to replace the biphosphate of lime by 3 per cent of phosphate of ammonia; but I much prefer the following mode of operating, which consists in adding 5 per cent of biphosphate of lime in solution to a solution of hydrochlorate of ammonia, evaporating the mixture carefully to dryness, and introducing the mass into the clay retorts. By this means the compounds of iron are completely decomposed, the whole of the iron remaining in the cylinders as phosphate of iron, whilst the sublimed sal-ammoniac is free from that injurious substance."

Carbonate of Ammonia.—Carbonate of ammonia is obtained in an impure form in the distillation of animal matter; but the chief sources are the preceding salts, either of which may be employed in the following process.

Both salts must be carefully dried, as in the case of making

sal-ammoniac, and if the muriate is employed, it must be intimately mixed with from 1½ to 2 parts of finely ground perfectly dry chalk and a small quantity of wood charcoal. This mixture is thrown into a retort *a*, Fig. 416, and exposed to a heat sufficiently strong to partially flux it. It must also be occasionally stirred to assist the decomposition of the remaining portions of the muriate of ammonia. The flue *b* passes all round the retort, and the carbonate of ammonia passes through a leaden pipe *c* into a receiver *d*, formed of sheet lead, and consisting of three parts. There are two small holes at *e* and *f*, to enable the workman to keep the pipe clear and remove the condensing carbonate. A third hole is made at *g*, which must be kept open to allow the steam to escape. The receiver *d* is about 8 feet high and 4½ feet square, and is adapted to work about 12 cwt. of rough muriate of ammonia. The body is supported by a strong framework *h*, and the under part by another independent framing *i*, while the top is removed by a chain and pulley attached to the hook *k*. The condensed water, charged with carbonate of ammonia, flows off through a cock *m* at the bottom. The rough carbonate lines the sides of the receiver to the depth of about 3 inches, and in this apparatus 13 cwt. of the rough muriate will produce about 9 cwt. of rough carbonate of ammonia.

FIG. 416.



Unless the receiver is very large, there is a considerable loss of the salt, which is carried off uncondensed by the steam at *g*. The mixing requires also much attention, for when carelessly performed, there is danger of some of the muriate subliming unchanged.

The rough carbonate obtained by the above operation is refined in the following manner. Two ranges of ten pots each, *aaa*, Figs. 417 and 418, very similar to those already described as employed in making sal-ammoniac, are fixed in metal cisterns *b b b*, which are filled with water to the level *c*, which level is maintained by an overflow at *dd*. A steam pipe *ff* passes along the bottom of these cisterns, perforated with small holes at the points corresponding with

the open spaces *gg* between the pots. The bulb of a thermometer *h* is immersed in the water so as to regulate the temperature, which

FIG. 417.

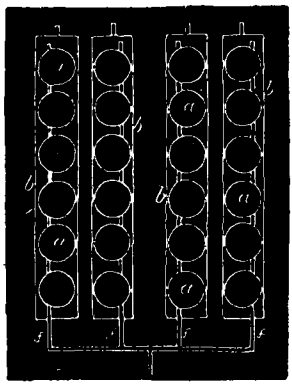
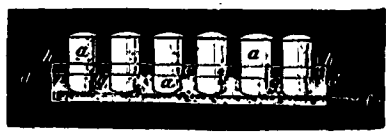


FIG. 418.



must not rise above 70° C. (158° F.) A higher temperature diminishes the quantity of merchantable salt, and injures the colour by subliming a portion of the colouring matter. The pots are charged with about 100 lbs. of rough salt, which only produces 50 to 70 lbs. of pure carbonate of ammonia.

Small square leaden chambers erected on pillars are sometimes employed in preparing the carbonate; these are connected with retorts set in a furnace in a similar manner to the retorts in the gas-house, and charged with sulphate or muriate of ammonia and carbonate of lime. The crude carbonate is resublimed from iron pots with leaden domes, heated by the waste heat from the same furnace. Ammonia and carbonic acid gases, when carried together into chambers of this description containing a solution of ammonia at the bottom, are proposed by Laming for preparing this salt, and when an excess of carbonic acid is used, the product is said to contain more carbonic acid than when prepared by the usual process of sublimation.

The carbonic acid used in this process is prepared by heating oxide of copper and charcoal to redness in a cast-iron retort, and when one charge ceases to evolve carbonic acid, the finely-divided reduced copper becomes converted again into oxide by exposure to the air. The gas thus obtained may also be passed through the ammoniacal liquor of the gas-works, when sulphuretted hydrogen is evolved from the sulphide until the whole has been converted into carbonate.

The commercial carbonate when freshly prepared is not quite uniform in composition, but is generally considered a sesquisalt, containing—

		Phillips.	Rose.	
			I.	II.
3 eq. carbonic acid .	55.93	54.2	50.55	63.4
2 „ ammonia . .	28.81	29.3	26.66	30.7
2 „ water . . .	15.26	16.5	20.79	15.9
	100.00	100.0	100.00	100.0

The purified salt contains less carbonic acid, and has, according to Rose, the following compositions :—

5 eq. carbonic acid	51
4 „ ammonia	31
4 „ water	18
	100

The salt loses ammonia by exposure to the air, and becomes bicarbonate, which has not the same powerful odour.

Scanlan considers the commercial sesquicarbonate a mixture of anhydrous carbonate and bicarbonate of ammonia, the former passing off on exposure, and also by washing with cold water, the bicarbonate being left in both cases.

According to Muspratt, the quantity of ammoniacal salts manufactured in 1853 was—

	Tons.
Sulphate	4500
Muriate	3800
Carbonates . . .	1700

of which a considerable portion was consumed by agriculturists.

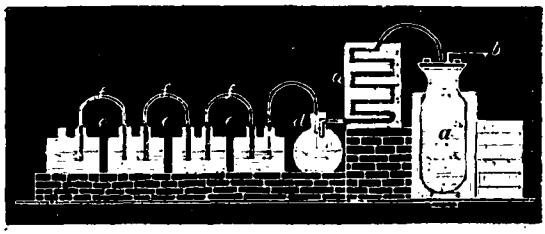
The importance of ammonia in agriculture is being daily recognised by farmers, and more especially in districts where the land is partially or wholly undrained, with a short summer and a cold uncertain climate. Dr. Anderson has recently drawn attention to the development of the sources of this important alkali, nearly the whole of which, as at present produced, is obtained from the manufacture of coal-gas; but from various causes at least one-half is lost, and his object is to suggest how the gas-water from the smaller works might be saved.

Caustic Ammonia: Liquor Ammoniæ.—The residuum from the last and all the other processes is finally employed in the preparation of liquid ammonia. These products are mixed with milk of lime in excess and heated in a deep retort *a*, Fig. 419,

upwards of 8 feet from top to bottom, to prevent the fluid from boiling over into the pipes.

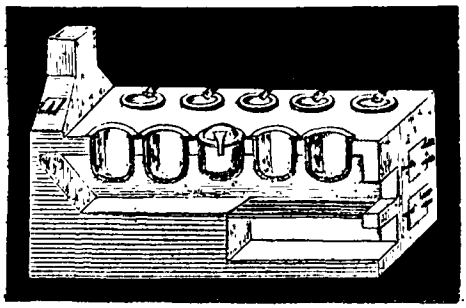
Mr. Lawson describes an arrangement in which the gas is conducted through upright iron pipes, placed in a cool situation, over the still, when the whole of the steam in combination with the gas is condensed, and falls back into the still. The upper lid, which

FIG. 419.



may be removed from time to time, is fitted with a safety-valve *b*, slightly loaded to prevent accidents. The gas is cooled in the worm *c*, and washed by passing through water in *d*. It then passes through stone-ware, lead, or gutta-percha tubes into a series of Woulfe's bottles *e e e*, where it is absorbed, producing a liquid of .86 specific gravity. The absorption generates great heat, so that it is necessary to keep these bottles in a stream of cold water. It is also a prudent precaution to attach a safety-valve to each connecting pipe *f f f*. As water condenses in the cold about 500 times its bulk of this gas, and increases in volume in the proportion

FIG. 420.



of 6 to 10, the bottle must not be more than three parts filled with water. The specific gravity falls from 1.000 to 0.875, which liquor contains 34.694 per cent dry ammonia. The crude solution thus obtained is allowed to stand for some time, when a flocculent matter of unknown composition settles to the bottom of the stone

vessels. When made from gas-water, although sufficiently pure for dyers' use, the liquid ammonia still contains some of the more volatile constituents of the tar, which often gives the solution a pink colour when it is neutralised with an acid.

Fig. 420 represents the arrangement adopted for distilling ammonia on a small scale in Germany, consisting of a series of metal pans heated by one fire. A glass retort, charged with the materials, is placed in each pan, and a series of receivers attached for condensing the ammonia.

Mr. J. J. Griffin has constructed a very useful instrument, in the form of a common hydrometer, for manufacturers of ammonia, which he terms an *ammonia-meter*. It is based upon the fact, experimentally proved by himself, that mixtures of anhydrous liquid ammonia and water possess a specific gravity which is the mean of the specific gravities of their components. He finds that in all solutions of ammonia 212½ grains of anhydrous ammonia, or one *test-atom*, displaces 300 grains of water, and reduces the specific gravity of the solution to the extent of .00125; and that one gallon of the strongest liquid ammonia which can be prepared at 62° F. contains 100 such test-atoms of ammonia.

We extract the following paragraph from Mr. Griffin's paper in the Transactions of the Chemical Society explanatory of the accompanying table:—

The first column shows the *specific gravity* of the solutions; the second column, the *weight* of an imperial gallon in pounds and ounces; the third column, the *percentage* of ammonia by weight; the fourth column, the *degree* of the solution as indicated by the instrument, corresponding with the number of *test-atoms* of ammonia present in a gallon of the liquor; the fifth column shows the number of *grains* of ammonia contained in a gallon; and the sixth column, the *atomic volume* of the solution, or that measure of it which contains 1 test-atom of ammonia. For instance, 1 gallon of liquid ammonia, sp. gr. .880, weighs 8 lbs. 12.8 ozs. avoirdupois; its percentage of ammonia, by weight, is 33.117; it contains 96 test-atoms of ammonia in 1 gallon, and 20,400 grains of ammonia in 1 gallon; and lastly, 104.16 septems, containing 1 test-atom of ammonia. Although no hydrometer, however accurately constructed, is at all equal to the centigrade mode of chemical testing, yet the ammonia-meter and the table accompanying it will be found very useful to the manufacturer, enabling him not only to determine the actual strength of any given liquor,

but the precise amount of dilution necessary to convert it into a liquor of any other desired strength, whilst the direct quotation of the number of grains of real ammonia contained in a gallon of solution of any specific gravity will enable him to judge at a glance of the money-value of any given sample of ammonia.

TABLE OF LIQUID AMMONIA.

One Test-Atom of Anhydrous Ammonia = NH_3 weighs 212.5 grains.
Sp. Gr. of Water = 1.00000. One Gallon of Water weighs 10 lbs. and contains 10,000 Septems. Temperature 62° Fahr.

Specific gravity of the liquid ammonia.	Weight of an imperial gallon in avoirdupois lbs. and ozs.	Percentage of ammonia by weight.	Test-atoms of ammonia in one gallon.	Grains of ammonia in one gallon.	Septems containing 1 test-atom of ammonia.	Specific gravity of liquid ammonia.	Weight of an imperial gallon in avoirdupois lbs. and ozs.	Percentage of ammonia by weight.	Test atoms of ammonia in one gallon.	Grains of ammonia in one gallon.	Septems containing 1 test-atom of ammonia.
	lb. oz.						lb. oz.				
.87500	8 12.	34.694	100	21250.9	100.00	.93750	9 6.0	16.190	50	10625.0	200.00
.87625	8 12.2	34.298	99	21037.5	101.01	.93875	9 6.2	15.846	49	10412.5	204.08
.87750	8 12.4	33.903	98	20825.0	102.04	.94000	9 6.4	15.502	48	10200.0	208.33
.87875	8 12.6	33.509	97	20612.5	103.09	.94125	9 6.6	15.158	47	9987.5	212.77
.88000	8 12.8	33.117	96	20400.0	104.16	.94250	9 6.8	14.816	46	9775.0	217.39
.88125	8 13.0	32.725	95	20187.5	105.26	.94375	9 7.0	14.475	45	9562.5	222.22
.88250	8 13.2	32.335	94	19975.0	106.38	.94500	9 7.2	14.135	44	9350.0	227.27
.88375	8 13.4	31.946	93	19762.5	107.53	.94625	9 7.4	13.795	43	9137.5	232.56
.88500	8 13.6	31.558	92	19550.0	108.70	.94750	9 7.6	13.456	42	8925.0	238.09
.88625	8 13.8	31.172	91	19337.5	109.89	.94875	9 7.8	13.119	41	8712.5	243.90
.88750	8 14.0	30.785	90	19125.0	111.11	.95000	9 8.0	12.782	40	8500.0	250.00
.88875	8 14.2	30.400	89	18912.5	112.36	.95125	9 8.2	12.446	39	8287.5	256.41
.89000	8 14.4	30.016	88	18700.0	113.64	.95250	9 8.4	12.111	38	8075.0	263.16
.89125	8 14.6	29.633	87	18487.5	114.94	.95375	9 8.6	11.777	37	7862.5	270.27
.89250	8 14.8	29.252	86	18275.0	116.28	.95500	9 8.8	11.444	36	7650.0	277.78
.89375	8 15.0	28.871	85	18062.5	117.65	.95625	9 9.0	11.111	53	7437.5	285.71
.89500	8 15.2	28.492	84	17850.0	119.05	.95750	9 9.2	10.780	34	7225.0	294.12
.89625	8 15.4	28.113	83	17637.5	120.48	.95875	9 9.4	10.4490	33	7012.5	303.03
.89750	8 15.6	27.736	82	17425.0	121.95	.96000	9 9.6	10.1190	32	6800.0	312.50
.89875	8 15.8	27.359	81	17212.5	123.46	.96125	9 9.8	9.7901	31	6587.5	322.58
.90000	9 0.0	26.984	80	17000.0	125.00	.96250	9 10.0	9.4620	30	6375.0	333.33
.90125	9 0.2	26.610	79	16787.5	126.58	.96375	9 10.2	9.1347	29	6162.5	344.83
.90250	9 0.4	26.237	78	16575.0	128.21	.96500	9 10.4	8.8083	28	5950.0	357.14
.90375	9 0.6	25.865	77	16362.5	129.87	.96625	9 10.6	8.4827	27	5737.5	370.37
.90500	9 0.8	25 493	76	16150.0	131.58	.96750	9 10.8	8.1580	26	5525.0	384.62
.90625	9 1.0	25.123	75	15937.5	133.33	.96875	9 11.0	7.8341	25	5312.5	400.00
.90750	9 1.2	24.754	74	15725.0	135.13	.97000	9 11.2	7.5111	24	5100 0	416.67
.90875	9 1.4	24.386	73	15512.5	136.98	.97125	9 11.4	7.1888	23	4887.5	434.78
.91000	9 1.6	24.019	72	15300.0	138.99	.97250	9 11.6	6.8674	22	4675.0	454.54
.91125	9 1.8	23.653	71	15087.5	140.85	.97375	9 11.8	6.5469	21	4462.5	476.19
.91250	9 2.0	23.288	70	14875.0	142.86	.97500	9 12.0	6.2271	20	4250.0	500.00
.91375	9 2.2	22.924	69	14662.5	144.93	.97625	9 12.2	5.9082	19	4037.5	526.32
.91500	9 2.4	22.561	68	14450.0	147.06	.97750	9 12.4	5.5901	18	3823.0	555.56
.91625	9 2.6	22.198	67	14237.5	149.25	.97875	9 12.6	5.2728	17	3612.5	588.24
.91750	9 2.8	21.837	66	14025.0	151.51	.98000	9 12.8	4.9563	16	3400.0	625.00
.91875	9 3.0	21.477	65	13812.5	153.85	.98125	9 13.0	4.6406	15	3187.5	666.67
.92000	9 3.2	21.118	64	13600.0	156.25	.98250	9 13.2	4.3255	14	2975.0	714.29
.92125	9 3.4	20.760	63	13387.5	158.73	.98375	9 13.4	4.0116	13	2762.5	769.23
.92250	9 3.6	20.403	62	13175.0	161.29	.98500	9 13.6	3.6983	12	2550.0	833.33
.92375	9 3.8	20.046	61	12962.5	163.93	.98625	9 13.8	3.3858	11	2337.5	909.09
.92500	9 4.0	19.691	60	12750.0	166.67	.98750	9 14.0	3.0741	10	2125.0	1000.00
.92625	9 4.2	19.337	59	12537.5	169.49	.98875	9 14.2	2.7632	9	1912.5	1111.10
.92750	9 4.4	18.983	58	12325.0	172.41	.99000	6 14.4	2.4531	8	1700.0	1250.00
.92875	9 4.6	18.631	57	12112.5	175.44	.99125	9 14.6	2.1438	7	1487.5	1428.60
.93000	9 4.8	18.280	56	11900.0	178.57	.99250	9 14.8	1.8352	6	1275.0	1666.70
.93125	9 5.0	17.929	55	11687.5	181.82	.99375	9 15.0	1.5274	5	1062.5	2000.00
.93250	9 5.2	17.579	54	11475.0	185.18	.99500	9 15.2	1.2204	4	850.0	2500.00
.93375	9 5.4	17.231	53	11262.5	188.68	.99625	9 15.4	0.9141	3	637.5	3333.30
.93500	9 5.6	16.883	52	11050.0	192.31	.99750	9 15.6	0.6087	2	425.0	5000.00
.93625	9 5.8	16.536	51	10837.5	196.08	.99875	9 15.8	0.3040	1	212.5	10000.00
						1.0000	10 lbs.	Water.	0		
1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.

Coal-tar Naphtha; Pitch-oil; Pitch-coke.—From every ton of coal distilled for the manufacture of gas, there are obtained from 10 to 12 gallons of tar, the conversion of which into permanent gas has puzzled the ingenuity of inventors since the first introduction of gas illumination on a large scale, and still remains an unsolved if not an insolvable problem. The proximate ingredients of this black liquid, which occupies the lowest position in the tar tank below the ammoniacal water, are probably very numerous, and must vary considerably with the varieties of coal, and the mode of conducting the distillation. The greater number are compounds of carbon with hydrogen, which cannot be rendered permanently gaseous, and are so nearly allied in physical properties that they can only be imperfectly separated from each other by repeated fractional distillations. Runge, Hofmann, Mansfield, and others, have succeeded in ascertaining the presence of the neutral, basic, and acid constituents, given in the table, p. 732, by treating the coal-tar naphtha successively with acid and alkali, and finally repeatedly distilling the mixture of neutral ingredients, of which far the greater proportion of the naphtha is composed, in such a manner as to collect those portions which boil at about the same temperature.

Of these numerous products, the neutral hydrocarbons alone are of commercial importance, and as these can only be completely separated from each other by tedious processes of distillation, they are employed in a state of mixture. The portions boiling at comparatively low temperatures are valuable, partly for their solvent powers upon gum-resin, gutta-percha, caoutchouc, &c., and partly as illuminating agents in naphtha lamps: these undergo a purification from the basic and alkaline constituents. The portions boiling at higher temperatures, *pitch* or *dead oil*, are used in the crude state in which they leave the still, for the preservation of timber. The pitch which remains is either converted into asphalte, or employed in the manufacture of patent fuel (p. 133), but neither of these applications being extensive, much remains as a drug on the hands of the manufacturer, and is now often converted into coke, yielding at the same time a further portion of oil, which is distinguished as *coke oil*.

SUBSTANCES DISTILLED FROM COAL-TAR.

Therm. Scales. Cent.	Fahr.	Neutral.	Basic.	Acid.	
?	?	Chrysene = H_6C_{12} ? } Yellow			Pitch
?	?	Pyrene = H_6C_{15} ? } Powder			
?	?	Paranaphthaline = $H_{12}C_{30}$. (Wax-like solid)			
300	...	.....	.....	.....	
	570				
	540				
280					
	462	.....	Leukoline = NH_8C_{18}		"Dead Oil" (heavier than Water)
239		Various liquid hydro-			
	430	carbons.			
220					
212	414	Naphthaline H_8C_{20} (Wax-like solid)			
200	...	.....	.....	.....	
	390				
187	369	.....	.....	Carbolic or Phenic Acid = $H_6C_{12}O_2$ (Crystalline solid)	"Naphtha" (lighter than Water)
182	360	.....	Aniline = NH_7C_{12} (Oily liquid)		
171	340	Cymole = $H_{14}C_{20}$ (Oily liquid)			
148	298	Cumole = $H_{12}C_{18}$			
113	235	Tuluole = H_8C_{14}			
111	232	.....	Picoline = NH_7C_{12}		
100	212	(Water boils)			
80	176	Benzole = H_6C_{12} (Spirituous liquid) (Solid at 0° C. = 32° F.)			
	160				
70		? Alliaceous Spirit =			
50		H?C?S?			
	120	.....	.....	.....	
		.....	Pyrrol ?		

Several other basic ingredients are doubtless contained in the naphtha. By neutralising the acid which is employed in its purification, a basic liquid is obtained, which, after 10 successive fractional distillations, yields about the same amount of product for every 5° of Fahrenheit's thermometer from below the boiling point of water up to about 360°, above which temperature the product gradually diminishes in quantity. The quantities of basic product is extremely small, not more than about 3 gallons of crude base having been obtained in one experiment from 500 gallons of naphtha, and that was diminished at least one-half in the process of purification.

Coal-tar Naphtha.—The processes employed in preparing naphtha and pitch-oil from tar have already been alluded to in describing the manufacture of patent fuel (p. 133), but no mention was there made of the purification to which the crude naphtha is submitted. The tar is distilled with about 1-5th of its bulk of water, or steam is blown into it as long as naphtha passes over with the condensed water; the former process yielding the best, the latter the most abundant product. In Scotland, where much cannel coal is distilled, the average yield of naphtha is about 10 per cent of the tar used; from Newcastle coal tar not more than 5 per cent is obtained, while some cannel coal tar is said to yield as much as 20 per cent of crude naphtha. The crude naphtha is mixed, in a large leaden dish capable of holding 500 gallons, with a small quantity of vitriol, with which it is well agitated, and which removes a considerable quantity of basic substances, ammonia, and water. This first portion of vitriol having been removed by a plug-hole at the bottom of the vessel, a larger quantity of vitriol, varying from 4 to 5 per cent of the crude naphtha, is added, which not only removes the remainder of the basic substances, but likewise chars or converts into resins those of the neutral oils which absorb oxygen, and turn brown when exposed to air and sun-light. The portions of the naphtha which are thus affected by oxidizing agents are those which boil between 140° and 200° C. (284° and 392° F.), cumole and cymole, according to the foregoing table, and also the alliaceous product boiling below 80° C. (176° F.) Much heat is generated by constantly stirring the vitriol during several hours with the naphtha, and sulphurous acid is evolved. The whole is then allowed to stand for some time, when the vitriol containing the altered hydrocarbons settles to the bottom of the tank, and is drawn off. The naphtha is then well washed with successive portions of water, and lastly with a dilute solution of caustic soda, containing milk of lime to remove the last portions of the acid and any acid products that also exist in the naphtha. The product thus obtained is now pumped into an iron still, and steam is blown through it, which carries over the greater portion of the naphtha. Both steam and naphtha vapour are condensed by an ordinary worm, and separate easily from each other, in consequence of their different gravities. A considerable quantity of naphthaline crystallises from the last portions which pass over. The rectified naphtha should not be exposed to light for some time after it leaves the still, or the small portions of water mechanically mixed with it will not

separate. In the dark, however, it soon becomes perfectly clear, and should then, if properly purified, stand the test of exposure to the sun's rays without acquiring colour. Coffey's still, described at page 291, appears admirably adapted for the distillation both of tar and naphtha, and has been used for that purpose in some manufactories, the trays and pipes being all constructed of iron instead of copper.

Crude naphtha distilled without water begins to boil at about 100° C. (212° F.), and continues to pass over liquid until the temperature reaches 200° C. (392° F.), when solid products begin to make their appearance. The rectified naphtha of commerce begins to boil at about 90° C. (194° F.), and about one-eighth of the liquid passes over before the temperature rises to 100° C. (212° F.); distillation continues up to about 160° C. (320° F.), when the retort generally becomes dry. The specific gravity of rectified naphtha ranges about .86, that of the different hydrocarbons of which it is composed varying from .85 to .87. If it be above .875, it is an indication of naphthaline or some heavy oils boiling above 200° C. (392° F.) being present. The most volatile portions of the naphtha, however, have a higher specific gravity than the less volatile, so that specific gravity cannot be taken as a test of volatility, which can only be estimated by the temperature at which the greater portion of the naphtha is converted into vapour.

Mansfield has obtained a patent for separating the different hydrocarbons enumerated in the table at page 732, from each other, by so arranging a number of different still heads or partial condensers to a single still, that each product shall be collected apart at about the temperature at which it boils. The separation is not completed in any single distillation, as the hydrocarbons are so closely allied that their vapours diffuse most easily into each other. By repeating the process of distillation, they can, however, be so far separated as to exhibit marked differences of physical character, and become applicable to different purposes.

Alliole, the most volatile of these bodies, is obtained by distilling crude naphtha, and collecting all that leaves the still in the first distillation, before the boiling temperature reaches 90° C. (194° F.), and on the second distillation all below 80° C. (176° F.); or, if a condensing head be employed with the still, by collecting all that passes before the temperature of the head has passed 60° C. (140° F.) This substance combines with, or is altered by, vitriol, and hence it is better obtained from

the crude naphtha, and afterwards purified by agitation with dilute sulphuric or hydrochloric acid, and redistillation. It boils when nearly freed from benzole, at a temperature of from 65° to 70° C. (149°—158° F.), and possesses an alliaceous odour somewhat resembling sulphuret of carbon. It is an excellent solvent, alone or mixed with an equal proportion of pyroxylic spirit, of caoutchouc, gutta-percha, shellac, and many resins.

Benzole, or *benzine* $C_{12}H_6$, the substance first obtained by Mitscherlich among the products from the dry distillation of benzoate of lime, forms a considerable and probably the most valuable portion of coal-tar naphtha. It may be separated sufficiently pure for many purposes by distilling rectified naphtha in a still with a head enclosed in a vessel of water, and so constructed as to allow all the vapours that have higher condensing points than 100° C. (212° F.) to fall back into the still. The naphtha being heated in the still by direct fire, the vapours ascending to the head soon cause the water to boil; alliole, benzole, and small quantities of the next most volatile hydrocarbon, toluole, pass over, while the less volatile cumole and cymole vapours are condensed and returned to the still. The alliole and toluole may be separated in great measure from the benzole by collecting the first and last portions which pass over in a second distillation. If still purer benzole is required, the middle product from the second distillation is treated with one half pound of vitriol, and about an ounce of nitrate of soda or potash, to every gallon, which destroys the alliole, and oxidizes any portions of the hydrocarbons which turn brown on exposure. A little nitric acid may also be used, which communicates a pleasant odour to the product by forming some nitro-benzole. The acid, and the substances separated by it, having been allowed to subside, the benzole is thoroughly washed with water. The product should then begin to boil at 80° C. (176° F.), and be entirely volatilized at 100° C. (212° F.) If required perfectly pure it is again treated with vitriol and some oxidizing agent, washed with water and lime-water, again distilled, collecting those portions only which pass over between 80° and 85° C. (176°—185° F.), and lastly submitted to a temperature some degrees below the melting point of ice, by a freezing mixture, when the greater part will congeal to a mass of crystals; these are submitted to powerful pressure at the temperature of 0° C. (32° F.), and the solid portion then melted, and, if necessary, again put through the same process of congelation and pressure. The product should then be entirely converted into vapour

between 80° and 82° C. (176°—179°.6 F.) It produces a state of intoxication, when inhaled, similar to that produced by ether, and may be used in many cases as a substitute for that substance. Pure benzole dissolves iodine, wax, quinine, fat and volatile oils. When a current of air is passed through it, so much of its vapour is taken up as to afford a very luminous flame when ignited, and the cruder kinds of benzole are proposed by the patentee to be used in this manner in the lamps and burners described at page 510. The less pure benzole, which contains alliole and toluole, may also be used as a solvent in preparing varnishes, all the substances mentioned as soluble in alliole being dissolved also by benzole. When gutta-percha is dissolved in benzole, and the solution spread on a smooth surface, the benzole speedily evaporates, leaving a tough film, which may be peeled off, and affords an artificial membrane applicable to many useful purposes; and when applied to the surface of the human body, an artificial skin is produced.

Nitrobenzole.—Benzole is not destroyed by concentrated oil of vitriol, but is converted by fuming nitric acid, sp. gr. 1.5, into *nitro-benzole* ($C_{12}H_5NO_4$),—a substance in which one equivalent of the hydrogen of the benzole is substituted by the peroxide of nitrogen (NO_4). Nitric acid is placed in a capacious glass vessel, surrounded by cold water, and the benzole in about an equal quantity is added to it, until two layers of liquid begin to appear; the vessel is then removed from the cold water and gently warmed until the two layers have united to a clear solution; the whole is then thrown into six times its bulk of cold water, when a heavy yellow or red oil sinks to the bottom. This is the nitro-benzol, which is repeatedly washed with water, and may be distilled without decomposition at a temperature below 220° C. (428° F.) This substance boils at about 210° C. (410° F.), possesses a very agreeable odour of bitter almond oil, and is useful as a perfume especially applicable to soap, and in small quantity to confectionary.

Toluole ($C_{14}H_8$) is obtained by collecting the last portions of the distillate from crude benzole, and purifying it with oil of vitriol, which has no effect upon it, while it destroys the hydrocarbons having higher boiling points. The portions of naphtha boiling from 90° to 110° C. consist principally of this substance, which, when pure, boils at about 110° C. (230° F.), and is capable of conversion, like benzole, into an aromatic oil by nitric acid.

Camphole.—The oils boiling at 140° and 170° C. (284°—338° F.),

called respectively cumole and cymole in the table, are collected together and called collectively *camphole* by Mansfield. These oils no longer take fire when an ignited match is plunged into them, and they are thus distinguished from the more volatile toluole and benzole; they continue to distil over from the crude naphtha until the boiling point in the still has reached 190°, or 200° C. (374°—392° F.) The specific gravity of crude camphole ranges from .88 to .98, and the less volatile portions frequently contain naphthaline, which raises their specific gravity. Camphole is strongly acted on by sulphuric acid, which converts the cumole into a viscid resinous substance; nitric acid converts it into a heavy oil, or into acid substances; the oil is rectified by repeated distillation, separating each time the first and last portions from the great bulk of the product, and then treating it with a strong solution of caustic alkali, to remove creosote and acid bodies, and subsequently with a dilute acid. This substance, either alone or mixed with pyroxylic spirit, is applicable for burning in lamps, or for dissolving resins as a substitute for oil of turpentine.

Pitch or Dead Oil.—The residue in the still after the whole of the naphtha has been separated is called distilled tar. It is sold as such to a considerable extent, and employed for coating ships and painting woodwork that is to be exposed to the weather. The greater part, however, is again submitted to distillation without water, at a high temperature, in strong wrought-iron vessels exposed to the direct action of the fire. The product which comes over in this distillation varies as the temperature in the still rises; at first it exhibits a light yellowish-green colour, and a remarkable opalescence, which increases by exposure to air and light, until after some time it becomes bottle-green by reflected, and dark brown or red by transmitted light. The colour becomes darker and the consistence more viscid as distillation proceeds, and the last portions are often semi-solid. The odour which this oil possesses is peculiar and indescribable, and no success has as yet attended the attempts to remove entirely the colour and smell by repeated distillation or other means. Mansfield obtains a substance from this oil which he calls *mortuole*, by digesting the dead oil with strong alkaline ley, and subsequently with acid, and distilling. A nearly colourless product is said to be obtained by repeating these processes.

The colouring matter of dead oil is capable, according to Mr. Lewis Thompson, of combining with acids, and produces then a crimson colouring matter quite equal to anything ever obtained

from cochineal. The colour is, however, destroyed, or converted into a yellow, by alkalies, and the attempts made to fix it upon silk or cotton have not been successful. The odour of dead oil is chiefly due, according to the same authority, to a peculiar alkaloid, which can only be compared with essence of soot, and which may be extracted by condensing muriatic acid gas in the oil, and subsequently washing it with warm water. The water then extracts the muriate of the alkaloid, which may be precipitated by ammonia.

After being twice distilled, and steam driven through the product to expel naphtha and naphthaline, the dead oil may be treated with 10 per cent of its bulk of vitriol in a kind of churn, in which the two liquids can be thoroughly incorporated with each other for a considerable time; the vitriol being then removed by subsidence, the oil is washed with water and treated in a similar churn, or rotating vessel, with caustic alkali, and again washed; by then again distilling and collecting at different stages of the process, three products are obtained,—a light or lamp oil, a lubricating oil, and paraffine. The first two require still to be boiled with an acidulous salt or dilute acid, and exposed in shallow trays at a temperature of 80° F. for some days, to remove or change the character of the odour which they still retain. The paraffine. may be purified by acid and pressure, as previously described. The author of the "Chemistry of Gas-lighting"* states that 100 gallons of dead oil treated in this manner will furnish about 10 gallons of lamp oil, 36 gallons of lubricating oil, and 46 lbs. of impure paraffine, yielding on purification from 16 to 18 lbs. of the pure article.

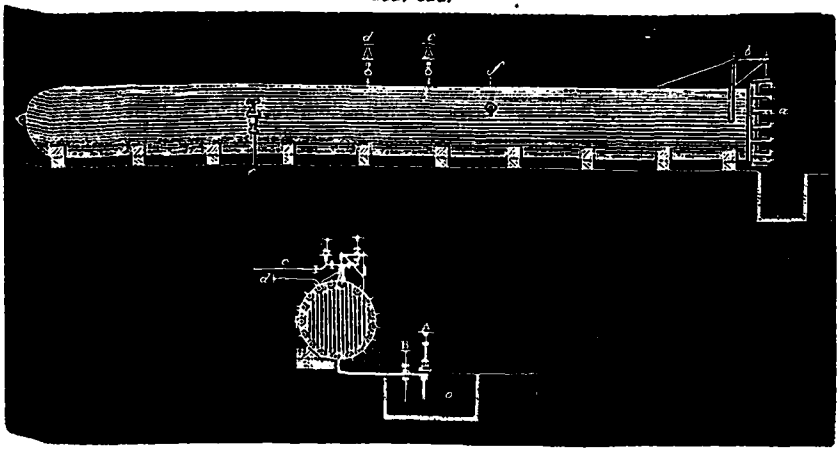
The process just described appears too troublesome and costly to enable the products to compete with Young's paraffine oil; and it is not even found profitable to make paraffine for the market from Young's oil, or from the residues left at a higher temperature in Young's process, which contain a much larger proportion than the dead oil of the tar-works.

Wood preserved by dead or pitch oil.—The principal technical use of pitch or dead oil is in the preservation of timber, particularly that which is required for railway sleepers, water-works, and the piles of piers, harbours, and bridges. Extensive establishments are erected in many large coast towns for forcing this liquid into the pores of the timber, upon a plan patented by Mr. Bethell. A strong wrought-iron cylinder, shown in Fig. 421, was at first employed with a door *a* capable of being moved by a crane *b*.

* Journal of Gas-lighting, vol. iii. p. 240.

The timber being placed in the cylinder, and the door screwed on so as to be air-tight, the air is exhausted by a powerful pump in connection with the valve *c*. The pitch-oil is then introduced, and powerful pumps are employed to force the oil into the heart of the wood. The lower drawing, Fig. 421, shows an end view of the apparatus. A is a sluice and safety discharge valve, B valve and

FIG. 421.



pipe to force-pumps from tank, C pipe through which the air is exhausted, D steam pipe, *e* oil-tank. In using this apparatus the water contained in the pores of the wood was found to offer such a serious obstacle to the introduction of the oil, even when immense pressure was employed, that little more than 4 lbs. of oil could be introduced into each cubic foot of wood, and this quantity was insufficient to render it permanently durable. The patentee has since found, that by drying the wood thoroughly by exposing it in a chamber to the smoke and vapours from a furnace, and immersing it while hot in a bath of the oil, as much as 7 or 8 lbs. of oil could be introduced into each cubic foot, which is thus rendered almost indestructible. Railway sleepers, impregnated with oil in this manner, remain unimpaired after years of immersion in wet situations, and the piles of piers and ship-timbers similarly treated are not attacked by sea-worms. The more porous the wood, the more oil it absorbs. The cost of creosoting wood is, on an average, something less than 4d. per cubic foot.

Carbazotic Acid from Pitch-oil.—Mons. Quinon has applied the dead oil obtained at the temperature of 160° to 190° C.

(320°—374° F.) to the preparation of carbazotic acid. He heats 3 parts of nitric acid of 36° B. (1.31 sp. gr.) to a temperature of 60° (140° F.) in a capacious vessel, and gradually adds one part of dead oil, having previously discontinued the application of the heat. After the addition of the oil, as much more nitric acid as was at first used is mixed with it, the whole heated to the boiling point, and evaporated to the consistence of a syrup. This solution, diluted with water to the necessary shade of colour at a temperature of 30° or 40° C. (86°—104° F.), is employed directly, without any mordant, for colouring silk, and the silk thus dyed is not washed, but immediately dried. In order to obtain the picric acid crystallised, it is necessary to dissolve the syrup in water—boil and crystallise several times, before it is pure. In this state it is still far from perfectly free from all impurities: it must be combined with ammonia, precipitated by muriatic acid, washed with water, dissolved in boiling water, and allowed to crystallise as the solution cools.

Pitch.—The distillation in the pitch still might be carried on until little but carbon remained in the still; but this would require a very intense heat, destroy the material of the still, and involve cost in removing the very hard carbonaceous residue which would be left. It is therefore only carried on to such an extent as to allow of the pitch being run off while hot from the still into a pond constructed to receive it. On cooling, the pitch solidifies, and is broken up into blocks.

The tar affords about 30 to 40 per cent of pitch-oil, leaving 60 to 70 per cent of pitch. 3000 gallons are distilled at once, and the charge is worked off in from twenty to twenty-four hours.

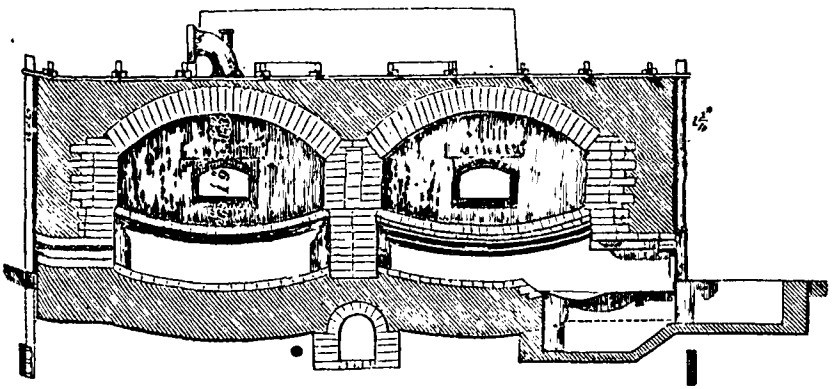
Pitch is jet black, and breaks with a very beautiful conchoidal fracture. No use has yet been discovered for this beautiful product, which lies in enormous heaps in many tar-works, much to the inconvenience of the manufacturer. In many places it has been employed as an ingredient of artificial asphaltum for foot pavements, and the paving stones of causeways have been laid in pitch, which renders them very durable. Messrs. J. Prentice and Co. have also largely introduced it in making floors for granaries, barns, &c. Pitch is also one of the principal ingredients in Ritchie's roofing felt, being used with asphalte and oil to give consistence to a kind of loose batt made from refuse tow and hair. The loose cloth is passed through heated rollers in a bath of the bituminous matter, and afterwards submitted to heavy pressure, which renders it compact and waterproof.

For footways the pitch is ground up with 50 per cent of stone, and the two are melted together, and, when laid down, mixed with 50 per cent of gravel, so that the finished way contains about 30 per cent of pitch.

Pitch-ovens; Pitch-coke; Coke-oil.—Pitch is now often submitted to further distillation in ovens constructed of refractory fire-bricks, when it affords about 25 per cent of what is termed coke-oil, 50 per cent of pitch-coke, 25 per cent of the original pitch being lost in the process.

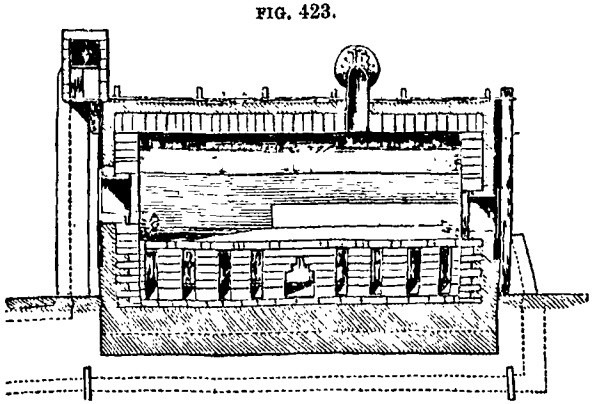
The pitch ovens are shown in the drawings, Figs. 422, 423, 424, 425, and 426. Fig. 422 is a longitudinal section of a pair of

FIG. 422.



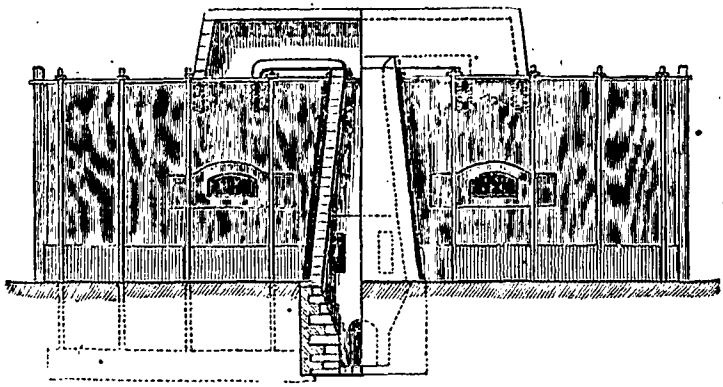
ovens built back to back, showing the grate and flues for heating them from below, the doors for charging, and the pipe through which the volatile products escape. Fig. 423 is a cross section

FIG. 423.



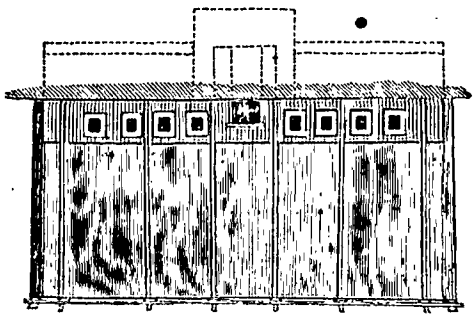
of one oven, showing a series of parallel flues under the sole of the oven, and the varying levels of the doors on each side. Fig. 424 shows a side elevation, with the manner in which the

FIG. 424.



heating flues communicate by an underground channel with a chimney, and also how above the working doors a small chimney carries off the smoke and vapours evolved at a certain stage of the process to the underground flue. Fig. 425 is an end elevation of

FIG. 425.



e oven, and shows, as do the other drawings, the manner in wh e brickwork is bound together with cast-iron plates and stro ought-iron girders, without which it could not withstand t ense heat to which it is subjected. Fig. 426 shows a plan of t r of ovens taken at different levels in each, with the manner ich the flues are carried below them.

Each oven is charged with about 2 tons of pitch through one e side doors, which are then closed by an iron plate, cemen

and clamped on in the same manner as the doors of gas retorts: the fires having been previously lighted, and the ovens still hot from the previous charge, volatile matters soon make their appearance, and are condensed and conducted by an iron pipe exposed

FIG. 426.

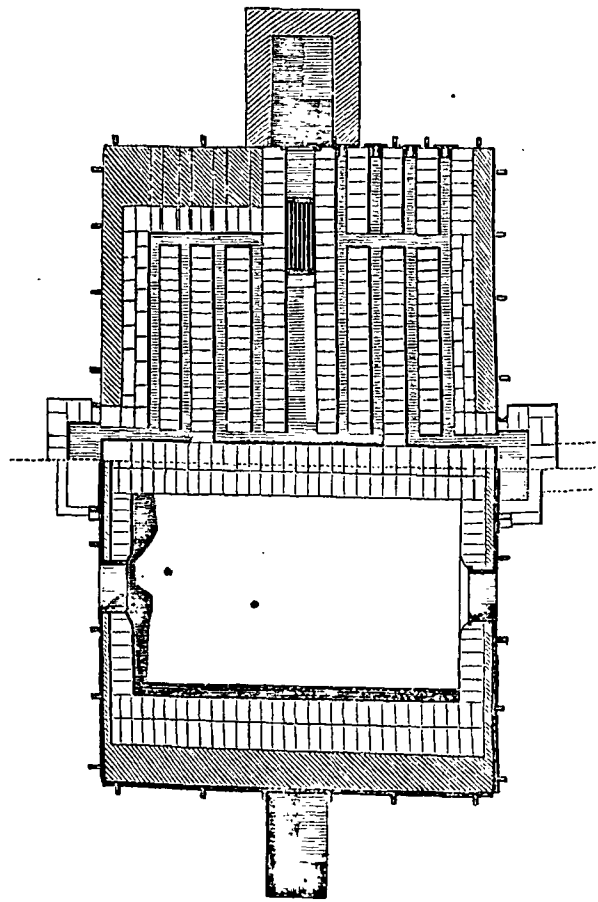


FIG. 426.

to the air, about 30 yards long, to a tank where the oil collects. At first an oil similar to the last portions of that collected from the pitch still comes over, but the subsequent products soon change in character, becoming more viscid, very dark-coloured, and with the appearance of having been burned. Towards the end of the operation, which lasts about twelve hours, yellow vapours in great quantities come over, which partially condense to a very

thick sticky mass, or sometimes into a reddish-yellow pulverulent substance, which, however, often becomes soft and sticky on exposure to the air. This appears very like the chrysene or pyrene noticed in the table at page 732, but has not been yet sufficiently examined. The coke-oil is added to the pitch-oil for creosoting purposes.

After about twelve hours, nearly the whole of the volatile matters have been evolved; the doors of the oven are then opened, and, being at different levels, a current of air is soon established through the ovens, which burns away the large quantity of carbonaceous matter that has become deposited on the roof and sides. A dense smoke is at first produced on opening the doors, which is conveyed to the underground flue by the short chimneys shown in the side elevation of the ovens. The cold current of air causes the layer of coke which is left on the sole of the oven to split up into fragments; and this is assisted by iron rakes and tools with long handles, with which the workmen remove it, while still red hot, from the oven. Exposed to the air it soon cools, and from its great density does not waste by burning. It has a remarkable appearance, being filled with small vesicular cavities left by the gases escaping through it while in a state of fusion. It is especially valuable for iron-founding and similar purposes, in consequence of its total freedom from any of the compounds of sulphur, and from ashes.

Soot, Lamp-black, &c.—The luminosity of every flame depends upon the separation of a portion of charcoal which is afterwards burned: this subsequent combustion may be very readily impeded by cooling the flame or diminishing the draught of air, when, in addition to the true products of combustion, empyreumatic vapours escape in conjunction with solid carbon in the shape of smoke, and which, when allowed to collect, forms soot or lamp-black, according to the nature of the substance burned and the mode of collecting it. A strong current of air causes the flame of a candle to smoke, and a porcelain plate or a plate of metal, held in it, becomes coated with soot:—in both cases this is the result of cooling. In all fires the combustion is imperfect, in consequence of the burning substances being too much cooled, and a defective supply of air. The internal walls of chimneys and flues become coated with various kinds of soot or black; near the fire this assumes the form of a blackish-brown, shining, varnish-like layer, consisting of dried tar with a little

charcoal (3.8 per cent, Braconnot) which, after undergoing preparation, is used as a pigment (bistre), and also to preserve meat from putrefaction. The soot deposited in the more distant parts contains much more carbon, and forms a brown flocculent mass. These are the only kinds of soot yielded by wood; but those substances which contain little oxygen and abundance of carbon, and which burn with a powerfully luminous flame,—such as resin, fats, oil of turpentine, pitch-oil,—deposit a kind of soot, which consists principally of charcoal, mixed with a little tarry matter; the quantity of the latter being less in proportion to the time which has elapsed before the soot is deposited, or in proportion to its distance from the flame. This product, when prepared from resinous wood, is called *pine-wood black*. It is of a deep black colour, and from the chemical indestructibility of the charcoal (except by combustion) is one of the most valuable opaque colours; its production has consequently been made a special process of manufacture. There is an extensive application for black pigments as ingredients of printers' ink, for the purposes of lithography and copper-plate printing, the manufacture of blacking, &c., for some of which it is required in the most minute state of division and purity, while in others it may be used in its ordinary condition. Braconnot found in 100 parts of pine-wood black—

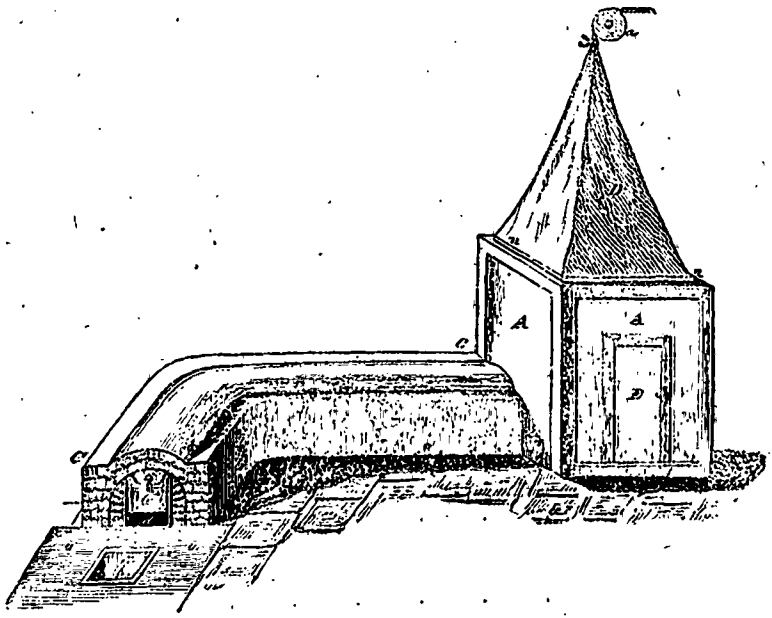
Carbon		79.1
Empyreumatic resin	soluble in alcohol	5.3
	insoluble in alcohol	1.7
Humin		0.5
Sulphate of ammonia		3.3
„ lime		0.8
„ potash		0.4
Phosphate of lime		0.3
Water		8.0
Sand (accidental)		0.6
Chloride of potassium		a trace.

Reichenbach found also naphthaline. The fixed salts present were really constituents of the ash carried over with it.

For making the common qualities of black, refuse resinous matters of all kinds are used. Those parts of fir-wood which abound in resin, and remain after the resin or colophony has been strained off; fir-leaves, chips, rubbish, &c., covered with resin; lastly, bark, leaves, &c., upon which resin has dropped,—these are collected when the fir-trees, from which the resin is obtained, are cut down. The mode of obtaining the black from

these substances consists in burning them with a very limited supply of air, sufficient only to consume the hydrogen and a part of the carbon, leaving another portion of the latter unburned, which is then deposited as pine-black. Fig. 427 represents the simple furnace used in Germany for carrying on this process.

FIG. 427.



A flue of brickwork *C C*, 2½ feet wide, connects the fire *d* with the soot chamber *A*; the length of the flue is at least 14 feet, to allow the inferior tarry black to deposit before the purer portion. The wood is burned at the one end of the flue *C*, the aperture of which can be either opened or closed for the proper regulation of the draught, by means of a movable iron plate *e*. In front of the plate *o* there is a pit *f* for the reception of the charcoal. Two kinds of black are obtained in this kiln, one of which has a brown hue, and is derived from the woody portions, and a jet black, or true pine-wood black, from the resin. The arrangement of the flue and chamber is adapted to separate the two, the former being deposited in the canal *C*, and the latter alone in *A*, provided the flue *C* has been sufficiently heated. As soon as this is effected, a charge of the wood (⅛ cwt.) is introduced, and the plate *e* is closed. The light soot collects at the back part, partly on the walls

of the chamber *A*, which has a capacity of from 2000 to 3000 cubic feet, but mostly in the hood *D*. The latter is a kind of roof composed of loose woollen cloth, extended by a rope passing over the pulley *a* at the top, and by the heavy frame *nn* at the bottom; it can also be lowered into the chamber. About 3 cwt. of black can be collected in this apparatus in ten hours. In a properly-conducted process, the temperature of *A* should always be somewhat lower than that of the smoke; but in time this relation becomes reversed, which renders it advisable to work only every other day, that the furnace may cool in the meantime. Another precaution is made requisite by the black itself, which, by its deposition, gradually impedes the draught; for it is evident, from the construction of the furnace, that no outlet is provided for the gases except through the substance of the hood itself, which, as it were, strains the soot from the various gases. The workman is consequently obliged to shake off the soot from time to time into the chamber by gently tapping the hood. The extremely fine state of division of the fresh black gives it, especially when warm, a dangerous tendency to inflame spontaneously on exposure to the air, and the chamber must therefore always be allowed to cool before anything is removed from the door *E*.

The loose uppermost soot which has fallen from the hood is separated as a finer article, for making printers' ink, from that which coats the walls of *A*, and forms ordinary lamp-black. Sometimes, instead of a single chamber with a hood, the soot is deposited in several successive ones; in this case, the last will contain the finer kinds.

In the coal districts, caking-coal forms a useful material for this manufacture, which is sometimes carried on in connection with coke-ovens, or with an arrangement for collecting the tar. In England a somewhat different method is practised from that which has been described, and which is common in Germany, the chamber with its hood being replaced by a series of tall bags, about 3 feet in diameter, and stretched perpendicularly. The flue conveying the smoke opens into the first bag at the lower and lateral part, which is connected with the second by a tube above, and the second with the third by a similar pipe at the lower and lateral part, and so on. The lateral connection is made below, so that the (tin) mouth-pieces of the bags with their capsular lids remain free, and can be occasionally emptied of the lamp-black. The last bag finally opens into a chimney. In this arrangement

the lamp-black is much better sorted according to the fineness of its quality.

Production of Lamp-black with and without Tar.—The preparation of common lamp-black from the refuse small coals is intimately allied to the process of coke-burning. In some cases it is combined with the manufacture of coal tar, and consists of the following arrangements. Fig. 428 shows a furnace *a*, in which small coal is consumed with the admission of as little air as possible; the heat and smoke pass through the openings *b b b*, round an iron or clay retort *c c* into a flue *d*, which is about 500 feet long, with many bends *e e*. The lamp-black is deposited in these flues or caves *e e*, and the retort *c c*, which is filled with coal, is heated from the furnace *a* so as to distil the coal tar, which passes through the cask *f* into a larger cistern communicating with the underground flue *g*. The inflammable gases pass off from the cistern and are burnt in the open air. The details of working this process are so simple that further explanation is unnecessary. A similar arrangement for making lamp-black without tar resembles Fig. 428 (page 750), with the omission of the retort *c c*.

The presence of several empyreumatic resins in lamp-black, some of which belong to the acid, but the greater part to the neutral class, seriously deteriorates its quality, causing it to burn with flame, and yield empyreumatic oil when heated with exclusion of air. They interfere with its application by imparting a brown instead of a pure black colour, and by preventing its being moistened with water. It is consequently necessary to mix the impure lamp-black with brandy, whenever it is required as an addition to water-colours. The removal of the empyreumatic resins by solvents cannot be carried out on a large scale; for they are usually only imperfectly soluble in alcohol, or in caustic alkali, and Braconnot only succeeded in removing the entire amount present (7 per cent) by means of ether and oil of turpentine. One of these solvents, the ether, is too expensive, and the turpentine requires a second operation to re-obtain it. In cases, therefore, where they are prejudicial, as, for instance, in lamp-black for lithographic ink, &c., it is preferable to destroy the resins by a red heat.

A very crude method of destroying the empyreumatic bodies is sometimes practised, which consists in burning the lamp-black with a limited supply of air. A tub filled with the soot is buried in the earth, the lid being level with the surface; a thick pole is then

introduced into the middle, which must be carefully withdrawn, when it leaves a perpendicular hole, into which a roll of tow, saturated with oil of turpentine, is pressed, and then ignited. When the lid is put on, a slow and smouldering fire spreads, until at last the whole of the soot is heated to redness. During this process, the tarry ingredients burn at the expense of a portion of the soot, about one-tenth to one-fifth being consumed. A better plan is to press the soot into a large tin case, placed within a cast-iron vessel like a gas-retort. The latter is bricked in over a fire, and the vapours of the decomposed tar conveyed by a conducting tube into the fire, where they serve as fuel.

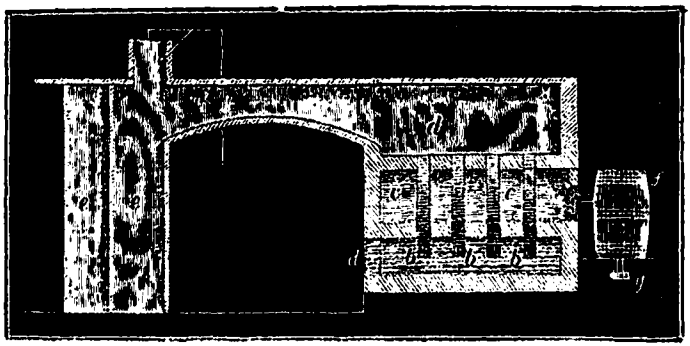
Black of greater purity, and in a much finer state of subdivision, is obtained from fixed oils—oil of turpentine, resin, pitch oil—when these substances are burnt in lamps, or as already described at page 137. When a lamp is used it is placed under a tin hood, which carries off the smoke by a lateral tube into chambers, or condenses the soot on its inner walls. The most profitable method of cooling is that of holding metallic plates in the flame, provided they are not allowed to become too hot. For this purpose, Prechtl proposed a roller of tin, which revolves in the flame, and rubs laterally against a brush, so that the soot is constantly brushed off, and fresh cool parts of the metallic surface are brought into the flame.

Inaccurate reports and fabulous accounts have left much doubt concerning the true nature of Indian ink. It is principally composed, however, of lamp-black of inconceivable fineness, and Prechtl considers it more than probable that it is prepared from camphor by the same process as lamp-black, the cementing matter being some kind of animal gelatine.

In manufacturing lamp-black according to the German method, about one-eighth of the residue of strained pitch is obtained as lamp-black; the produce from fir-wood is of course much less, because the woody portions are chiefly converted into tar. The quantity which theoretically ought to be obtained from a given amount of material cannot well be determined, because the process is not definite and constant, but is entirely dependent upon the management of the draught of air and the nature of the material. There is not the least doubt that the lamp-black is derived from that portion of the carbon which, during the process of decomposition, is carried away by the hydrogen. Common coal, the

hydrogen of which amounts to only 5 or 6 per cent, yields considerably less black than oils, resins, or camphor, six-ninths to eight-ninths of the weight of coal on an average being left in the form of coke and taking no part in the decomposition, while no residue of charcoal is left by the latter, which contain two or three

FIG. 428.



times as much hydrogen. In most cases, a portion of the carbon in the material is consumed by the oxygen present; but with oil of turpentine, and some other oils in which oxygen is entirely absent, this does not occur, the oil containing nearly 18 per cent more carbon than is required to form olefiant-gas with its hydrogen.

Spanish black is obtained by the combustion or charring of cork. Vine black from the tendrils of the vine. Peach black from peach kernels. German or Frankfort black, used in copper-plate printing, is said to be obtained by carbonising a mixture of grape and vine lees, peach kernels, and bone shavings.*

Matches.—The most ancient method of obtaining fire was by the agency of friction applied to dry combustible substances; a method which is still practised among savage nations in warm climates. A small conical hole being made in a piece of dry wood, a pointed piece of the same substance is made to turn forcibly in it, like the axle of a wheel turning in a socket. Sparks are soon produced which will communicate flame to light inflammable substances. The wood of the ivy rubbed with that of the laurel are particularly recommended by Pliny for easily producing fire. Flint and steel were known to the Romans, and said to have been

* Tomlinson's Cyclopædia.

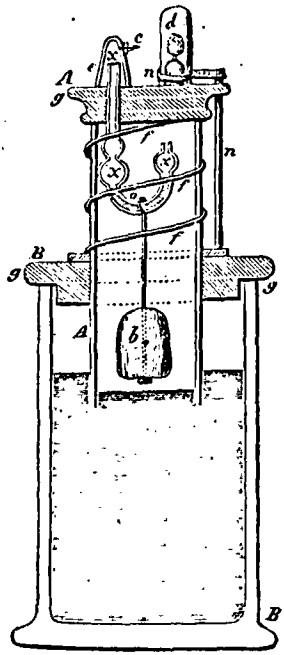
invented at Pyropolis in the island of Delos; what the tinder was which at first was employed does not appear. These continued the principal source of flame during the middle ages, and indeed till the middle of the 17th century, when the discovery of phosphorus, and of chlorate of potash at a later period, pointed to more rapid and ready sources of ignition. Flint, steel, and tinder, in conjunction with a sulphur match, remained however still very generally in use until the year 1820, when Döbereiner discovered the property which finely divided platinum possesses of inflaming a jet of hydrogen-gas in the air. This discovery attracted great attention at the time, but, from the costliness of the necessary apparatus for procuring light, has remained rather a curious than a useful invention; it may, however, have exerted an indirect action in leading inventors to seek a more instantaneous source of light than the old tinder-box.

The spongy platinum employed in Döbereiner's lamp is obtained by precipitating a solution of platinum in aqua regia (chloride of platinum) with muriate of ammonia; the platino-chloride of ammonium thus obtained is stirred with a little pure ammonia into a thick paste, a drop of which is placed upon one end of a thin platinum wire, which is made into a loop. By drying, and the subsequent application of a white heat in a spirit-lamp, the double salt is completely decomposed, the platinum remaining as a metallic, porous mass, resembling a cinder (sponge). Several metals possess the property of causing the ignition of hydrogen, but not in so eminent a degree as platinum, which, by some peculiar and inexplicable action on its surface, causes the combination of hydrogen with oxygen to form water at temperatures far below the usual point of ignition. This power increases rapidly with the extent of metallic surface; it is greater in thin coiled wire than in foil, and most active in spongy platinum in consequence of its porosity, or the large surface presented by a small bulk.* A current of hydrogen, mixed with air or oxygen, brought into contact with the platinum sponge, at once combines to form water; the sponge is raised to a white heat, and the gas then takes fire from the incandescent metal.

* Supposing the pores in a cubic line of spongy platinum to be $\frac{1}{100}$ of a line in diameter—which is far too much—and that these spaces were also cubical, there would be (independently of the thickness of the walls) a million of cells in the entire cube, each containing $\frac{1}{1000000}$; hence altogether $\frac{6000000}{1000}=600$ square lines; *i. e.* a surface 100 times larger than that of the solid cube. Thus an idea of the increase of surface obtained by porosity may be readily obtained.

A good arrangement of the apparatus proposed by Eisenlohr is shown in Fig. 429. The spongy platinum is placed under a cap of brass plate *d*, fastened to the wire *n* exactly opposite the aperture *c*, from whence, when the lamp is in use, a current of hydrogen issues. The latter is produced in the lower vessel *B B* from a mass of zinc *b* and sulphuric acid (diluted with six parts of water), and is accumulated ready for use in the upper movable vessel *A A*. As often as any of the hydrogen is consumed, a fresh supply is immediately produced, the zinc then coming into contact with the acid, while at other times it remains above the surface of the liquid as shown in Fig. 429. The upper movable vessel *A A* slides in the lid *g* like the piston of a pump, and when at rest is kept up by the spring *fff*; in that position, the only outlet for the accumulated gas, through the glass tube *x x x*, is closed by a few drops of dilute sulphuric acid at *o*. When *A A* is pressed down the gas contained in it forces the resisting fluid *o* into the bulbs, and opens an outlet for itself first into the cap *e*, which is firmly fixed to the lid of *A*, and thence to *c*, where it raises the spongy platinum to a white heat, and is then inflamed. On the escape of the gas, however, the acid simultaneously rises in *A*, and coming into contact with the zinc, replaces, by a further evolution of gas, that which has escaped. This process continues uninterruptedly as long as the quantities of zinc and acid are not exhausted. Other forms of this apparatus are employed, in which the upper vessel is a fixture. If the platinum sponge be exposed so as to collect dust, this, on using the instrument, will burn and clog the pores, which are also liable to be stopped up with the sulphate of zinc, which is carried off mechanically by the gas in very finely-divided particles. The sponge soon becomes useless from these impurities, although the quantity accumulated is very small; but this need not excite surprise when we know that the action of platinum-foil in electrical experiments may be destroyed by merely

FIG. 429.



wiping it with the cleanest cloth. According to Mohr, the sponge when spoiled may be restored by treating it with concentrated sulphuric acid, and washing with distilled water. An entirely new surface may be produced by first immersing the sponge in a solution of chloride of platinum, then in a solution of muriate of ammonia, and subsequently heating it to redness.

The sulphides of phosphorus, which inflame upon the least friction, were suggested at one time as sources of instantaneous light, but from the danger attending their production have never come into general use. The discovery of chlorate of potash, and the property it possessed of igniting combustible matters when brought into contact with oil of vitriol, led Captain Manby to use it as a means of firing the small piece of ordnance he employed for conveying a rope to a stranded vessel. Sulphur matches were then coated with a mixture of chlorate of potash and sugar, or with a composition of metallic sulphurets, resin, gum, &c.; these, when pressed into asbestos moistened with oil of vitriol, were ignited. The chlorate is decomposed by the vitriol into bisulphate of potash, perchlorate of potash, and chlorous acid; the perchloric and chlorous acids evolve chlorine and oxygen, which, combining with the combustible matters, produce fire. These went under the name of *chemical matches*.

The same principle was adopted in the Prometheans, in which the chlorate and the sugar were enclosed at the end of a small roll of paper with a very thin glass tube, containing oil of vitriol; by crushing the little glass tube with the teeth or a pair of pliers, the vitriol was brought into contact with the mixture, and flame produced, which communicated itself to the paper.

These matches are now superseded by the more simple lucifer matches, which inflame by mere friction, without the aid of acid.

Lucifer-matches.—The history of this invention, which dates from 1832, is already lost, notwithstanding its novelty. In the friction-matches, the primary coating of sulphur, or some very inflammable substance, cannot be dispensed with, because the igniting composition burns much too rapidly to set fire to wood. The flame produced by the combustible mixture is, therefore, first communicated to the sulphur, and from it to the wood. The mixture at first contained chlorate of potash and sulphide of antimony as essential ingredients, and the production of fire depended upon the sulphide being inflamed by friction when in contact with the chlorate. Phosphorus was subsequently substi-

tuted for the sulphide of antimony, and the mixture then required much less friction to ignite it. The phosphorus was mixed with gum or mucilage at a temperature of 104° F., so as to form an emulsion, to which the chlorate of potash was then added. The ingredients are always moistened before mixing, as the operation in the dry state is at all times dangerous. The unpleasant noise which occurred whenever a match was inflamed, and some danger from fire, rendered it desirable to replace the detonating action of the mixture by a slow combustion; and this has been accomplished in the *noiseless lucifer-matches*. None of those compositions which inflame *without* explosion contain chlorate of potash, but nitre and phosphorus instead, the latter of which burns at the expense of the oxygen of the former. The general principle concerned in the preparation of these matches consists in bringing substances like phosphorus, which have a great affinity for oxygen, into contact with others which contain a large amount of that element condensed into a small space, as is the case with nitre, so that the slightest cause is sufficient to effect their combination. The peroxides of lead and manganese, which abound in oxygen, are often mixed with the nitre; they give off oxygen very readily when they have once attained a red heat.

The wooden splints for the matches are cut by machinery, or planes constructed for the purpose; they are thus obtained thin, sufficiently strong, perfectly uniform, and of an elegant appearance. In 1842 a patent was taken by Partridge for forming wooden splints by pressing blocks of wood against a steel plate perforated with holes placed as closely together as possible. Moist poplar wood is best suited for this purpose. The round or angular matches are dipped in bundles into melted sulphur, and then coated with the inflammable composition. According to Böttger, 16 parts of gum-arabic, 9 parts of phosphorus, 14 parts of nitre, and 16 of finely-divided peroxide of manganese, form a good composition, which must be worked up with water, to avoid danger. The mixture then forms a thick paste, into which the matches are separately dipped and then dried. Occasionally, smalt and similar matters are added to produce certain colours, or to increase the effects of friction. After repeated trials, the inflammability of the composition has been gradually diminished to such an extent, that it only inflames when strongly rubbed against rough surfaces, but not readily by pressure or shaking, especially when the matches are preserved in closed boxes; hence they are much less dangerous

than might be anticipated. Böttger also gives the following recipe for the inflammable mixture:—

Phosphorus	4
Nitre	10
Fine glue	6
Red ochre or red lead	5
Smalt	2

The slow combustion of the sulphur, with the emission of sulphurous acid, which is both disagreeable and injurious, forms a great objection to these matches. Others have since been introduced into commerce which have been first dipped into fused stearine or white wax instead of sulphur. Small wax, or stearic acid tapers, covered at one end with a similar composition, have lately also become common under the name of Vesta-matches.

The manufacture of matches has been brought to great perfection in Germany, where Darmstadt took the lead, and since the prohibition, which existed in many of the States of the Union up to 1840, has been removed, the development of this branch of industry, in the Austrian States in particular, has been very rapid and extensive. In the Grand Duchy of Hesse Darmstadt there are eight manufactories, producing weekly about 500,000 boxes of matches, valued at £257. The matches manufactured in Austria in 1849 amounted to 50,000 cwt., of which four-fifths were consumed at home, and one-fifth exported. Two-thirds of these were made in Bohemia, and the other third in the neighbourhood of Vienna.

One Bohemian factory, employing 100 workpeople, produces annually about 200,000 boxes, each containing 5,000 matches. It consumes annually 25 cwt. of nitre, 6½ cwt. of phosphorus, and 300 cwt. of sulphur. The splints are chiefly cut at Budweis, with astonishing rapidity, by a simple plane of peculiar construction, with which a single workman cuts 1,814,000 in twelve hours.

In France, according to Payen, 590 cwt. of phosphorus are annually consumed in the manufacture of matches, while 2 cwt. suffice for all other purposes.

The manufacture of matches containing phosphorus exposed the workmen engaged with dipping the match into the inflammable mixture to a most terrible disease, attributed to the vapours of the phosphorus, and attended by great pain and swelling of the jaws,

followed, in many instances, by exfoliation of the bone. It has been observed, that by great cleanliness and thorough ventilation in the factory, this may be in great part, if not entirely, prevented. But the discovery of amorphous phosphorus by Schötter, which has been found quite as applicable to matches as the ordinary modification, will completely do away with any chance of a recurrence of this terrible malady. This substance, which is of a red colour, amorphous, not volatile or oxidisable at ordinary temperatures, and can be handled without danger, is now made in large quantities by Messrs. Sturge, of Birmingham; and matches prepared with it, quite equal to the common matches, were exhibited in 1851.*

Electric Light.—Although foreign to the subject of fuel, it may not be uninteresting to say a few words on the light produced by the agency of electricity. The electric current has been proposed at various times as a source of artificial light, and has been employed in two distinct modes, which have been indiscriminately called electric lights. The one method consists in simply breaking the circuit or conducting medium, and employing different solid electrodes at short distances from each other, when the passage of the current between the two is attended with a brilliant evolution of light. In some cases very thin metallic sheets of the most incombustible metals, as platinum, have been rendered incandescent by the passage of the current, and the light thus evolved transmitted by reflectors in different directions. At others, charcoal points, constructed with the hardest graphite, prepared either artificially or from that which is deposited in the interior of gas retorts, are made the electrodes, and placed at very short distances from each other in a vacuum, to prevent the combustion of the charcoal, when the passage of the current from the one to the other produces, with a Grove's battery, the most brilliant light. The chief difficulty in applying this light, apart from economic considerations, is its want of steadiness, which arises at times from the inconstant nature of the current, at others in the irregular waste of the charcoal, portions being carried from the one electrode to the other, and the form of the charcoal points, as well as the intermediate distance, being thus subject to constant change. Great ingenuity and the most persevering industry have been manifested

* For the statistical information above, we are indebted to the Reports of the Juries of the Exhibition of 1851, to which we refer for more full particulars.

by Mr. Staite and others in applying mechanical contrivances to obviate these difficulties, but no system has yet been rendered sufficiently simple and easy of management to render this brilliant light generally available. For light-house purposes its great intensity would be most valuable; the fluctuations, however, if not brought under control, are such as must preclude its use where such serious consequences might result from irregularity. The question of cost, however, will, as far as we can judge, be an insurmountable obstacle at present to the introduction of this light for ordinary purposes. Although Mr. Grove calculated, some years ago, that for acid, zinc, wear and tear, &c. of batteries, a light equal to 1444 wax candles could be obtained for about 3s. 6d. per hour, the cost of the light employed for about five minutes at Her Majesty's Theatre, as an incident in the ballet, which was obtained by employing 75 cells of Callan's batteries of the largest size, was said to be £2 per night, or at the rate of £20 per hour. The light exhibited by Mr. Staite from the summit of one of the piers of Hungerford Suspension Bridge was said to be equal to 750 candles. The same patentee constructs apparatus for domestic use, capable of producing light equal to from 8 to 40 candles; but of the relative cost of the light in these different degrees of intensity we are unable to form an estimate.

The other application of the electric current as an indirect means of producing artificial light, is by employing it in the decomposition of water, or some substance which yields hydrogen gas by electrolysis. The hydrogen is then rendered luminous by being saturated with oil of turpentine or naphtha vapour, in the manner already described under naphthalised gas. As hydrogen can be obtained in other ways than by the electric current, at considerably less cost and trouble, there does not appear much prospect of success from this mode of generating the gas, unless it be obtained as an accessory or secondary product in some other remunerative application of the electric force.

APPENDIX.

APPENDIX.

WHAT IS COAL?

The question, "What is Coal?" has been lately prominently brought forward by Dr. Fleming with reference to a substance familiar to all the world, and yet so ill defined that the most costly litigation has arisen from our ignorance of what is understood by the term. After consulting the accumulated information of the preceding pages, the first impression is, that there ought to be no difficulty in defining what coal is; but the records of the causes, "Abraham Gesner *v.* William Cairns," and "Gillespie *v.* Russel," lead to a very different conclusion. Some of the remarks of Dr. Lardner, in a recent number of the "Museum of Science and Art," on "Our Notion of Time," are very applicable to the case in question. "The most simple," he says, "of our notions are those which it is most difficult to describe or define. Locke observes, with his usual felicity and clearness, that a word which expresses a single idea does not admit of definition, inasmuch as a definition, being a sentence composed of two or more words having different significations, cannot collectively express one idea which has no composition at all. The only way to convey to the mind of another the meaning of such a word, is by presenting to his senses the object or quality which it expresses." But even this *argumentum ad hominem* does not dispose of the important question, What is coal? for different eminent authorities deny that anthracite on the one side, and Boghead cannel on the other, can be regarded as coal; a conclusion at which the members of the Royal Society of Edinburgh appear to have arrived,—an unanimous opinion having been expressed, at a meeting on the 6th of February, to the effect that, in the present state of science, it is impossible to determine what coal is. At a recent meeting in Edinburgh of some of the most distinguished geologists, chemists, botanists, and mining engineers, the following definition was discussed, which Dr.

Redfern adopted in a paper read at the British Association in Liverpool last year, viz.—*Under the term coal those substances must be comprised which consist of compressed and chemically altered vegetable matter, associated with more or less of earthy substances, and capable of being used as fuel*;—a definition with which we are disposed to agree.

This definition demands a careful microscopical examination of a mineral before it can be pronounced coal; and we are fortunate in being able to present a most interesting inquiry on this point by our friend, Dr. Aitken, of Glasgow; previous to which, however, we propose to examine the subject in its geological, mineralogical, mining, chemical, and technical aspects.

Coal in a Geological point of view.—For the following sketch of the geology of coal we are indebted to Mr. Jukes, Director of the Geological Survey in Ireland.

Geologically speaking, coal is a stratified rock, always found in beds interstratified with other stratified rocks, clays, sandstones, and limestones. The only difference between coal and clays, sandstones and limestones, is, that while they are formed principally of mineral matter merely enclosing organic remains, coal is formed principally or entirely of organic remains.

The organic remains may have, in some few instances, formed parts of animals, but in the great majority of instances (so great as to be nearly universal) the remains are those of plants. These vegetable remains, having been deposited in thick beds or layers, each layer extending over an area sometimes of many square miles, were covered up by other beds of sand or mud, and subsequently converted into coal. How this conversion took place is a question for the chemist to decide. Pressure no doubt aided it, and some degree of heat, but perhaps not a greater degree than would arise from the decomposition of the plants themselves. The thickness of the beds varies from a mere film or layer of a ¼ inch in thickness up to 3 or 4 feet. No single bed of coal, probably, is ever thicker than 3 or 4 feet, and rarely exceeds half that. Where a seam of coal reaches 8 or 10 feet, and *à fortiori* where it reaches 30 or 40, it is composed of two or three or more beds resting directly one on the other, or separated by thin layers of clay or earthy matter, which are commonly called "partings."

These thin layers of earthy matter,—fine mud originally,—are so frequent as to be almost universal in all beds of coal whenever

they are traced over any distance,—and *they* sometimes, even when not more than an inch or two in thickness, extend over areas of many square miles. They are the result of tranquil deposition of sediment in water, and prove the coal to have been under water at the time of the formation of the "parting." Beds of coal, which in one locality come together, resting one on another directly or with only the "intervention of a "parting," are in other places separated by many feet, or sometimes even many yards (30 or 40, for instance) of interposed beds of sandstone and clay. The same would be found to occur in all sedimentary stratified rocks, if any one or two beds of them were traced accurately over wide areas as beds of coal are by mining operations. There is, in short, no peculiarity or mode of occurrence in beds of coal which is not common to other beds of regularly stratified sedimentary rock.

We should, therefore, be at once inclined to decide that the materials of coal had been deposited under water, having been drifted into their present position, become water-logged and sunk, just as the materials forming sandstones and clays have been drifted and sunk to the bottom, were it not for some other circumstances which make it probable that coal was often the result of the deposition of the remains of plants on the spot where they grew, and that that spot was dry land. Every bed of coal, for instance, has under it a bed of clay,—usually fire-clay, but sometimes arenaceous, or even sandstone itself,—crowded with the remains of plants that are now known to be roots, and the roots of stems that are so frequently found associated with coal that they evidently contributed largely to its formation. Botanists tell us that these stems were not those of aquatic, but of land plants. Upright stems, moreover, of trees have been found under such circumstances as almost to prove them to be in the position of growth, and in some beds of coal that have been worked by "open work" (quarrying, that is to say), stools of trees have been found in abundance close together in the substance of the coal, and in ranks one above another in its different layers.

It is supposed, therefore, that many beds of coal were formed, not by drifted plants, but by plants that fell and died on the spot where they grew, that spot being afterwards depressed beneath the level of water from which the sedimentary masses of sandstone and clay were deposited upon them. It is probable that coal was the result sometimes of one, sometimes of the other method of accumulation.

The following is the graphic account of vegetation at the period of the coal formation, by Hugh Miller:—

"A low shore thickly covered with vegetation. Huge trees of wonderful form stand out far into the water. There seems no intervening beach: a thick ledge of reeds, tall as the masts of pinnaces, runs along the deeper bays like water-flags at the edge of a lake. A river of vast volume comes rolling from the interior, darkening the water for leagues with its sluice and mud, and bearing with it to the open sea reeds and fern, and cones of the pine, and immense floats of leaves, and now and then some bulky tree undermined and uprooted by the torrent. We near the coast, and now enter the opening of the stream. A scarce penetrable phalanx of reeds, that attain to the height and well nigh the bulk of forest trees, is ranged on either hand. The bright and glossy stems seem rodded like Gothic columns; the pointed leaves stand out green from every point, tier above tier, each tier resembling a coronal wreath or an ancient crown, with the rays turned outwards, and we see at top what may be either large spikes or catkins.

"What strange forms of vegetable life appear in the forest behind! Can that be a club moss that raises its slender height for more than fifty feet from the soil, or can these tall palm-like trees be actually ferns, and these spreading branches mere fronds? And then these gigantic reeds! Are they not mere varieties of the common horse-tail of our bogs and morasses magnified some sixty or a hundred times? Have we arrived at some such country as the continent visited by Gulliver, in which he found thickets of weeds and grass tall as woods of twenty years growth, and lost himself amid a forest of corn fifty feet in height? The lesser vegetation of our own country,—its reeds, mosses, and ferns,—seem here as if viewed through a microscope: the dwarfs have sprung up into giants, and yet there appears to be no proportional increase in size among what are unequivocally its trees. Yonder is a group of what seem to be pines, tall and bulky, it is true, but neither taller nor bulkier than the pines of Norway and America; and the club moss behind shoots up its green hairy arms, loaded with what seem catkins above their topmast cones.

"But what monster of the vegetable world comes floating down the stream,—now circling round in the eddies, now dancing on the ripple, now shooting down the rapid,—it resembles a gigantic star-fish, or an immense coach-wheel divested of the rim. There

is a green dome-like mass in the centre that corresponds to the nave of the wheel or the body of the star-fish, and the boughs shoot out horizontally on every side like spokes from the nave or rays from the central body. The diameter considerably exceeds forty feet; the branches, originally of a deep green, are assuming the golden tinge of decay; the cylindrical and hollow leaves stand out thick on every side, like prickles of the wild rose, on the red, fleshy lance-like shoots of a year's growth, that will be covered two years hence with flowers and fruit. That strangely formed organism presents no existing type among all the numerous families of the vegetable kingdom.

"There is an amazing luxuriance of growth all around us. Scarce can the current make way through the thickets of aquatic plants that rise thick from the muddy bottom; and though the sunshine falls bright on the upper boughs of the tangled forest beyond, not a ray penetrates the more than twilight gloom that broods over the marsby bottom below. The rank steam of decaying vegetation forms a thick blue haze that partially obscures the underwood. Deadly lakes of carbonic acid gas have accumulated in the hollows. There is a silence all around, uninterrupted save by the splash of some reptile fish that has risen to the surface in pursuit of its prey, or when a sudden breeze stirs the hot air and shakes the fronds of the giant ferns or the catkins of the reeds. The wide continent before us is a continent devoid of animal life, save that its pools and rivers abound in fish and mollusca, and that millions and tens of millions of the infusory tribes swarm in the bogs and marshes. Here and there, too, an insect of strange form flutters among the leaves. It is more than probable that no creature furnished with lungs of the most perfect construction could have breathed the atmosphere of this early period, and lived."

The varieties of coal may depend on the varied nature of the plants that composed it, the various circumstances attending their deposit, or the varied conditions under which the beds have subsequently been placed. If coal were formed under water, mud or earth may have been deposited along with it: if it grew above the level of the water, occasional floods may have brought in earthy matter over and among it. This we see in our peat-bogs at the present day. Many of the clays or shales in the "coal measures" contain a greater or lesser amount of carbonaceous matter intimately mixed up with them, and this occasionally to such an

amount that they will for a time support combustion and give off gas. This may be observed often in our parlour fires, in what are called "slates," but which ought to be called "shales," and which in Staffordshire and other coal fields are called "batts" or "basses." Some coals, moreover, have such an amount of earthy matter mingled with them that they support combustion but indifferently when compared with other coals. It hence arises that there is every possible gradation, arising from the mixture in various proportions of mineral and organic matter, from a mere clay up to the purest coal; and it would be quite impracticable to draw any line of distinction between a "carbonaceous (or bituminous) shale" and an "earthy coal." The same person would give the different names to the substance according to the subject or object he had in view.

Moreover, the same bed of coal which is earthy, impure, or "batty" in one place, will in another be a pure and excellent bituminous coal. By bituminous we must in all cases understand, not containing bitumen, but containing little else but the constituents of bitumen,—namely, carbon and hydrogen. All kinds and varieties of coal, therefore,—cannel, caking, stone, and anthracite,—graduate insensibly into each other, not only by different beds having different qualities, but sometimes by the same bed changing gradually in its different portions. Coal, therefore, although it may be said to be organic matter mineralised, cannot be called a "simple mineral," but a "rock," or mechanical mixture of substances in various proportions and degrees, those substances having become indurated and compacted together,—partly by mere pressure, partly by the chemical action of the constituents,—just as many sedimentary rocks, containing a variety of substances—calcareous sandstones, magnesian limestones, and ferruginous shales—have become changed, or "mineralised," so to speak, not only by pressure, but by the chemical reaction on each other of their several constituents. Their origin having been mechanical aggregation, their subsequent consolidation has been the result of the mechanical and chemical conditions under which they have been placed.

Coal is in Britain principally confined to a certain set of rocks, called the carboniferous, occupying a posterior place in the series of stratified rocks. Wherever that set of rocks has been found in other parts of the world, it has been also found to have beds of coal. Coal, however, is by no means confined to that set of rocks,

but is found in different parts of the globe in different parts of the series, from the Devonian down to the most recent tertiary rocks. In all periods of the earth's geological history, wherever an accumulation of plants took place, and that accumulation was properly buried under beds of sand and mud, coal was the natural and apparently the inevitable result.

Coal in a Mining point of view.—For the following remarks on coal-mining, and a miner's idea of coal, we are indebted to Mr. Reid, of Pelton Colliery:—

"If the age of a science may be judged of by the books that have been written upon it, the science of coal-mining may be reckoned amongst the earliest. Agricola, in his elegant work, 'De re Metallica,' refers to it; and the earliest edition of this book bears date so soon after the invention of printing, that it may be conjectured that a science which had attained so great an importance as mining possessed in his days, was the growth of many centuries, and required nothing but the knowledge of the art of printing to render it more fully known to the world.

"In so remote an age, it is vain now to ask, who was the first coal miner? For a reply to this we must go back to the days of the alchemists, and probably further, as, no doubt, the earliest mining operations would be, like alchemy, enveloped in the mysteries of magic; as may be evidenced in the earlier allusions to the virtues of the vigula or the divining rod.

"One thing, however, can scarcely be doubted, that so long as the primeval forests furnished the necessary fuel for the use of man, he would never be tempted to the toils and nausea of a search for that which is contained in the crust of the earth. Where and by what means he was first led to this, is lost in the mists of antiquity; but so far as Britain is concerned, there is excellent evidence in the structure of the language in all matters referring to mining terms, that from our Saxon ancestors we derived the earliest knowledge of coal and its uses.

"It is probable, therefore, that so soon as our Saxon ancestors fell short of the charcoal derived from their extensive forests (Holz Kohlen), they would probably have recourse to the (Tage-Kohlen), or surface-coal outcropping on the surface of the land: that this was the earlier subterranean fuel we have confirmatory proof in the distinction drawn between it and the fuel from the lignite formation (Braunkohlen) so abundant in Germany.

"Had lignite or brown coal been the earliest introduced into

commerce or to the wants of man, it is probable we should have had the term 'Schwartzkohlen,' or *black* coal, applied to the jetty bituminous article so generally used in England.

"If, then, the wants of man (so soon as the primeval forests failed him) forced him to search in the crust of the earth for the fuel wherewith to warm him in winter, and to cook his food,—so long as his wants were limited to these two necessary points he would content himself with that which was easiest obtained and least noxious to health.

"The science of mining, however, and especially of coal-mining, was destined to march with the luxuries and refinements of mankind; and, as civilisation increased, the coal-miner was told to search for those mineral fuels which were best adapted to his advanced condition.

"The invention of the steam-engine, the art of gas-making, the spread of steam navigation, and, finally, the invention of the railway, and its implied locomotive engine-power, have each opened out new uses to which subterranean fuel is best adapted, and for each of which coal of suitable nature was required.

"Hence, new paths had to be entered, and new investigations were required of the 'coal-miner,' who, in place of being *the substitute* of the 'hewers of wood' in the earlier stages of our history, had in the first instance to search for such a fuel, or coal, as would produce the greatest amount of steam in the shortest space of time at the least possible cost.

"So soon as he had fulfilled the task of providing a coal for the steam-engine, the chemist invented the luxury of gas to displace that of oil, which had hitherto been used so extensively to illuminate our towns and houses. Here, then, a new demand was made upon the energy of the coal-miner, and he was required to search for such a coal as would give the brightest light at the least possible cost, and with the least possible annoyance when introduced into domestic use.

"What would it matter, therefore, to the coal-miner, in his hunt or search for a gas-coal, what its colour was,—whether its fracture was conchoidal, or which way it lay in the mine,—or whether it looked '*chameleon-like*,' a stone or a shale, a slate or a cannel, or, in fact, anything but like the jetty black coal he had erst been used with, or like the Braunkohlen of his Saxon ancestors. So long as the substance he found made gas, and that gas in the

greatest quantity and of the highest illuminating power, his object was fulfilled.

"Again, when the locomotive and the railway began to thread the length and breadth of England, new duties and new demands were made upon the energies of the coal-mining engineer; and can it be doubted, that when the universal outcry was made against our rural scenes being contaminated by the dense black smoke of our bituminous coals, that if a fossil coke, or anthracite, had been discovered, *it*, in preference to all other coals, would have become the *locomotive coal par excellence?* The attention of the miner, instead of being diverted to rendering the coal he already possessed less noxious to the public by converting it into coke, would then have been realised in providing such a coal as was best suited for locomotive use.

"The mission of the mining engineer or coal-miner may, therefore, be most truly defined as the '*hewer of fuel*' to supply the wants and luxuries of mankind. In England such fuel has been most appropriately named *coal*. Had it been designated by any other name, few would have used it in the first instance; and any substance, not called by the name handed down from our Saxon ancestors, would have had many difficulties to struggle with in its introduction into commerce, however superior its qualities."

Mineralogical characters of coal.—The mineralogical characters of coal are very various. Anthracite appears to be almost amorphous and uncrystalline, while most other varieties break up into cubical or rhomboidal fragments. The fracture is either conchoidal, uneven, fibrous, or slaty; in some cases, as in Boghead, it is conchoidal perpendicular to the plane of stratification, but slaty when parallel.

The colour runs through all the shades, from light brown in the case of some of the Scotch cannels, to the velvet black of the caking coal of Newcastle, while the streak following the colour passes into a brownish yellow in some specimens.

Some varieties can scarcely be said to have any lustre,—as the Wemyss, Methil, and other cannels,—from which there is a gradual transition to the shining resinous caking coals, terminating with the splendent semi-metallic, and beautifully iridescent anthracites, with every possible variety between these extremes.

With reference to hardness, the anthracite variety, possessing a hardness of 2.0 to 2.5, perhaps stands at the head of the list, from which we descend through the difficultly-frangible splint of Glasgow,

the sectile cannels and jet, down to the brittle, soft soiling coals of the north of England.

The following table gives the range of the specific gravities of the different varieties:—

American—Rhode Island anthracite .	1.7500
Ditto, Pennsylvania „ . .	1.5500
Ireland—Kilkenny . „ . .	1.4354
Wales „ . .	1.3750
France—Canton of Lanton, near Prendle, anthracite	1.0720
England—Hetton caking . . .	1.2740
Ditto, Garesfield „ . . .	1.2800
Nova Scotia—Picton „ . . .	1.3250
France—Megecoste „ . . .	1.4900
America—Madisen Town caking . .	1.5600
Scotland—Glasgow splint . . .	1.2900
America—Johnson's Run ditto . .	1.4930
Turkey—Silivria 1.346 to Rodosto . .	1.5300
Scotland—Wemyss cannel . . .	1.1831
Ditto, Boghead „ . . .	1.1990
England—Ince Hall „ . . .	1.2550
Scotland—Rocksoles „ . . .	1.4480
America—Blossburg „ . . .	1.7500

Coal in a Chemical point of view.—The chemical composition of coal varies even more than the mineralogical characters, but, in one respect, substances acknowledged by one party or another to be coal, differ in not yielding bitumen to any of the numerous reagents which have been employed for this purpose.

Dr. Fyfe obtained the following results by acting upon different coals with naphtha:—

	Per cent of matter soluble in naphtha.
Newcastle caking	4.2 5.8 9.8
Cannel coal, No. 1	2.
Ditto No. 2	3.
Ditto No. 3	4.
Halbeith cannel coal	1.5
Capeldrae ditto	0.0
Torbane ditto (black) . . .	1.2
Ditto ditto (brown) . . .	1.4

The carbon varies—

From 70.12 per cent in Anthracite from Meissner to 94.10 per cent in that from Pembrokeshire.

From 56.77 per cent in Cannel from Capeldrae to 83.75 per cent in that from Incehall.

From 74.82 per cent in Splint from Wylam to 82.92 per cent in that from Glasgow.

But the same extremes do not exist in the bituminous coals.

The hydrogen varies to a much greater extent among coals generally, but not so much in coals of the same description. Thus we have 1.49 per cent in the anthracite of the Isère deposit, and 8.86 per cent in the cannel of Boghead.

The same remarks apply to the oxygen; no oxygen being present in some of the French anthracites, and as much as 15.51 in coal from the Dalkeith jewel seam. The most striking relation of these two elements exists in the Boghead cannel, where, with 8.86 per cent hydrogen, there is only 3.62 per cent oxygen; to which circumstance Mr. Lewis Thompson very properly attributes much of the peculiar value of this coal.

There is nothing very noticeable in the proportions in which the sulphur, nitrogen, &c., are present, especially as the former may exist either as sulphuret of iron, sulphate of lime, or in combination with the organic elements.

The quantity of ash varies much more than any of the other ingredients, which is quite consistent with the origin of coal: thus in—

Semi-bituminous coals we have from			2.80 to 23.69	per cent ashes
Bituminous	do.	do.	1.70 to 33.88	do.
Anthracites, American		do.	1.28 to 68.00	do.
British coals		do.	1.20 to 26.50	do.

which generally consist of the same ingredients, derived from the associated stratification, as the following analyses by Kremers and Tayler, and those previously quoted by Phillips, prove.

Constituents.	1	2	3	4	5	6
Silica	15.48	45.13	60.23	31.30	1.70	3.12
Alumina	5.28	22.47	31.63	8.31	2.12	29.50
Peroxide of Iron	74.02	25.83	6.36	54.47	60.79	32.78
Protoxide of Iron	...	...	...	...	...	...
Lime	2.26	2.80	1.08	3.44	19.22	20.56
Magnesia	0.26	0.52	0.35	1.60	5.03	2.16
Potash	0.53	0.60	0.11	0.07	0.35	0.99
Soda	...	0.28	...	0.29	0.08	1.72
Sulphate of Lime	2.17	2.37	0.24	0.52	10.71	9.17
	101.53	100.60	98.37	98.95	99.30	100.00

Constituents.	7	8	9	10	11
Silica	62.44	59.56	64.21	56.51	58.99
Alumina	31.22	12.19	28.78	31.89	26.19
Peroxide of Iron	2.26	15.96	2.27	...	5.14
Protoxide of Iron	...	...	...	7.04	5.11
Lime	0.75	9.99	1.34	1.69	0.67
Magnesia	0.85	1.13	1.12	0.85	1.54
Potash	2.48	1.17	2.28	1.38	2.34
Soda	...	...	...	0.61	...
Sulphate of Lime	...	...	...	...	...
	100.00	100.00	100.00	99.97	99.98

1. Glance coal from Oberndorf, near Zwickau.
2. Zwickau compact glance coal.
3. Zwickau light soft coal.
4. Waldenburg coal.
5. From the coal formation at the Inde.
6. Brown coal from Arlern.
7. Newcastle fire clay from between the coal seams.
8. Newcastle coal after deducting 8.2 per cent sulphuric acid.
9. Inferior ditto, after deducting sulphuric acid.
10. Shale after deducting 39.35 per cent organic matter.
11. Shale after deducting 11 per cent clay.

The following is the relation of silica and alumina (including other substances in small quantity) in the Scotch cannel coals :—

	Boghead.	Lesmahago.	Capeldrae.
Silica	69	48	53
Alumina, &c.	31	52	47
	100	100	100

When submitted to distillation all varieties of coal yield the same solid, liquid, and gaseous products, consisting of coke, tar, ammoniacal liquor, benzole, naphtha, naphthaline, paraffine, paraffine oil, and illuminating gas, the proportions among which vary with the quality of the coal and the temperature employed.

Coal in a Technical point of view.—The two great technical applications of coal are in the manufacture of coke and illuminating gas.

In respect to the first no coal yields a merchantable coke which does not cake, but all coals yield a residuum containing what is termed *fixed carbon*, more or less mixed with ash, as the table by Dr. Penny, of assays of cannel coals of Scotland, p. 572, exhibits in a very striking manner; and in this respect they differ from most shales, which leave no fixed carbon, as is shown by the table below, and by others at the end of the volume.

Shales, &c.	Stirlingshire Coal-field.	Pendleton, Lancashire.	Fife Rums.
Combustible matter .	16.53	22.53	26.74
Fixed carbon . .	. —	—	20.51
Ashes . . .	83.47	77.47	52.75
	100.00	100.00	100.00

A shale seldom contains more than 20 per cent of inflammable matter when the water it naturally contains is deducted, while the amount of ash averages from 82 to 83 per cent. Most shales yield little or no bitumen to naphtha, and in this respect they resemble coal; but there exist shales, properly called bituminous shales, that afford considerable quantities of bitumen.

Dr. Fyfe has shown,* by a numerous series of experiments, that the relation of volatile to non-volatile matter in coals of the most various description, omitting the anthracites, is from 37 to nearly 67 per cent, and the amount of coke yielded consequently varies from 33 to 63. The proportion of fixed carbon and of ash also varies, the former from about 18 to 52, and the ash from 3.6 to 28.5 per cent. These characters at once

* Journal of Gas-lighting, vol. iii. p. 588.

distinguish coal from bituminous shales, of which he furnishes the following analyses and comparison with the Torbane Hill cannel coal:—

TABLE OF THE COMPOSITION OF SHALES.

Shales.	Volatile matter.	Non-volatile matter.	Non-volatile matter.	
			Fixed carbon.	Ash.
Above Dysart iron-stone	19.	81.	7.	74.
Under Craig coal	7.8	91.2	6.	86.2
Roof of ditto	7.7	92.3	0.	92.3
Ditto of wood coal	7.	93.	8.	85.
West Wemyss	13.5	86.5	2.5	84.
Lancashire (1)	15.9	84.1	7.7	76.4
Ditto (2)	13.14	86.86	7.9	78.96
Ditto (3)	7.7	92.3	8.8	83.5
Average	11.46	88.53	5.98	82.54
Torbane mineral	69.	31.	12.	19.

As regards the manufacture of gas, the tables given in pages 575 to 579 confirm our statement, and we now add a table of results of the distillation of various coals on a small scale, which illustrate the same fact.

Names.	Coke.	Tar.	Water.	Ammonia.	Carbonic acid.	Sulphuretted Hydrogen.	Olefiant gas, and other Hydro-carbons.	Other gases, inflammable.	Authority.
Welsh coals—									
Graigola	85.50	1.20	3.10	0.17	2.79	trace	0.23	7.01	Admiralty Report.
Jones's anthracite	92.90	trace	2.87	0.20	0.06	0.04	?	3.93	
Oldcastle fiery-vein	79.80	5.86	3.39	0.35	0.44	0.12	0.27	9.77	
Ward's fiery-vein	...	1.80	3.01	0.24	1.80	0.21	0.21	...	
Binea	88.10	2.08	3.58	0.08	1.68	0.09	0.31	4.08	
Llangenneck	83.69	1.22	4.07	0.08	3.21	0.02	0.43	7.28	
Newcastle coals—			Gas water.				Total gas.		
Ramsay's cannel	68.79	9.02	0.73		1.33	0.52	19.61		Richardson.
Cowen's ditto	70.37	8.33	0.97		1.18	trace	19.15		
Wallsend caking	70.28	11.70	1.11		0.92	0.49	15.50		
Hutton seam ditto	74.99	8.77	1.23		1.00	0.26	13.75		
Walker ditto	72.47	11.00	1.06		0.35	0.48	14.64		
Pelaw main ditto	74.50	9.70	1.10		0.46	0 24	14.00		
Scotch coals—									
Edinburgh cannel	60.35	16.10	0.80		3.02	0.34	19.39		Brownell.
Boghead ditto	46.75	24.00	0.55		.20	trace	28.50		
Prussian Rhine	83.40	6.30	0.40		trace	0.08	9.82		

Microscopical Examination of Fuel.—For the substance of the following investigation of the microscopic structure of coal we are indebted to our friend Dr. Aitken, of Glasgow:—

The external characters of fossil fuel, as seen by the naked eye, are not always a sufficient index of the qualities of the substances, for two bodies apparently similar may be microscopically different.

The following series of allied bodies have been examined for the purpose of this enquiry:—

1. *Peat* and *turf* from England, Scotland, Ireland, and Germany.
2. The German and English *lignites.*
3. The Scotch and English *cannel* coals.
4. The English and American *gas-coal,* not of the cannel kind.
5. *Household* and *coking* coal.
6. Welsh and American *anthracites.*
7. Native *asphalt,* elastic *bitumen* and *shale.*
8. Simple *stratified mineral* bodies.
9. *Vegetable tissues* growing at the present day, and allied to the plants found in the carboniferous strata.

Before proceeding to the microscopic examination of fuel, it may perhaps assist our object to introduce here a few remarks on the scalariform tube or ladder-like tissue to which reference will often be made. In such tubes the deposit of cellulose seems to take place in such a way as to leave marks, bars, or fine lines running across the tube, so that the vessel appears as if broken up into spaces resembling the steps of a ladder. In ferns this tissue assumes a prismatic columnar arrangement. Receptacles of secretion exist also in some parts of plants, and consist of special canals or cavities containing oily, fatty, or resinous matter. Hard substances, which have received the name of sclerogenous or gritty tissue, also frequently fill the interior of cells, as in the pulp of the pear and hard part of shells. In some instances the organic portion of the tissue may be removed by nitric acid, and siliceous matter is left in the form of the original structure.

How far these and other elementary structures are preserved or altered during the process of transformation into coal or allied fossil substances, has now to be examined.

I. *Peat.*—Theories of the most varied kind have been proposed

to explain the nature and formation of peat; but the general conclusion is, that peat in its usual form consists of a matrix of vegetable matter, enclosing earthy material, and is for the most part made up of the fibres, roots, and leaves of many different species of plants.

Examined by the microscope, carefully selected portions from beds of peat show the process of transformation from the recently living vegetable fibre to the compact lignite, jet, or even coal itself. Distinct and characteristic microscopic appearances are associated with the carbonization of the varied materials and its farther transformations. The experiments of Lindley and Goepert show that the persistence of structure in plants immersed in water depends very much upon the power which particular families of plants possess of resisting the decomposing action of water.

The process of transformation becomes more and more apparent by the deposit of a black amorphous matter in and upon the walls of the cells, which under the microscope appears to be nothing but carbon, and at first occurs in a very definite manner. The granular deposit is noticed first in the interior of the cells and upon the walls of the tubes which compose the vascular tissue of the plants, so that the process of transformation appears to begin with these. This metamorphosis continues until the original anatomical appearance of recent vegetable tissue is completely destroyed, becoming opaque, granular, and amorphous by the deposit of the black substance.

The evolution of gaseous products ruptures the cells, and the vascular tissue becomes separated, so that the cells and fibres gradually pass into an amorphous mass of a black colour, or into a homogeneous yellow resinous-like substance.

These are the changes which result where the air is partially excluded, but when it is present the mass assumes a more earthy aspect, and the elements of the tissues moulder down into granular particles. The gaseous products, when they cannot bodily escape, tend to break up the tissues as they become confined within the cells or between the tubes. The burial of vegetable matter in the earth thus shuts out the action of the air, and exposes it to the action of mineral matter, either the result of its own decomposition or that of surrounding strata.

This process of change is very gradual, and is much influenced by local circumstances; some of the forests in our own country

which have been submerged prior to all tradition, still retain all their ligneous characters. The timber of a forest exposed on the sea-coast near Whitburn, in the county of Durham, had not suffered any important change in its microscopic vegetable character, except where it had been exposed to the decaying action of the weather. When stems of wood exist in the lowest strata of peat, as in many samples of the Allenhead Moor peat, it is completely blackened in colour, and easily reduced to a soft clay-like paste. When examined microscopically it presented an appearance characteristic of brown coal or lignite, retaining the granular or general form of woody tissue, as seen by the naked eye. The minute structure of the elementary vegetable tissue is completely obliterated and replaced in many parts by the black opaque matter already described. (Compare Plate A, Fig. 1.)

The process of hystolysis, or retrograde decay, has been artificially imitated by Goepert, who found his resulting matter could in no respect be distinguished from brown coal. Some portions escape, as the bark and silicious parts of the stem, as well as some kinds of plants, as the coniferæ and arducaria, or Norfolk Island pine, which perhaps owe their preservation to the antiseptic nature of the products of their decomposition. Their remains are often found forming the mineral charcoal, the mother coal or Faserkohlen of the Germans. Hatchett has noticed the same fact, and found that resin, next to woody fibre, most powerfully resisted all changes.

II. *Coal.*—When sections of the varieties of this substance are made and reduced to a uniform degree of thinness, so that if transparent they may be examined with transmitted light, with powers magnifying from 70 to 300 diameters, they will be found to present certain fixed and general features characteristic of some one of the particular class already named.

The great bulk of the household coals, including all the coking varieties, the anthracite and steam coals, are perfectly opaque throughout their substance, and can only be observed by reflected light.

The gas-coals, such as the Pelton, the Nova Scotia, with the cannels, brown coals, jets and lignites, are all more or less transparent, and hence microscopically there are only two varieties of coaly substance, viz. *the opaque* and *partially transparent.*

A transparent microscopic section of coal is seen to be composed of three very obviously distinct materials, differing in appearance

and properties. (See Figs. 6, 7, 8, Plate A; and Figs. on Plate B.) These materials are—

1. An opaque black substance.
2. A yellow or reddish substance.
3. An earthy matter sometimes more or less coloured.

The relative proportions in which these substances are associated evidently influence the various products derived from them. This is very obvious when the microscopic appearance is contrasted with the chemical constitution, and more especially with the gaseous liquid products of their distillation, and which would appear to be peculiarly dependent upon the yellow or reddish coloured substances.

The black substance corresponds microscopically in appearance, and in reaction, with carbon as it is known to exist in the granular or amorphous state in various mineral substances in nature. It is insoluble in sulphuric and muriatic acids, and dilute nitric acid, in caustic ammonia and potash, and chlorine is without any action upon the colour.

The third body named, the earthy matter, is more or less soluble in water, to which it sometimes communicates a colour, and consists chiefly of the substance known as umber.

The nature of the second substance is not so easily ascertained. Its colour varies from a light yellow to a bright red or amber-coloured resinous-looking matter. It is volatile by heat, and insoluble in oil of tar, naphtha, muriatic, and nitric acids. When free bitumen is present it colours the naphtha.

It may be generally stated that the black matter forms the chief and almost exclusive constituent of household and anthracite coals, while the yellow matter on the contrary enters most abundantly into the structure of gas-coal. It is also worthy of observation that the external blackness of the coal is no criterion of the presence or absence of the yellow matter, as shewn by the investigation of the nature and properties of the Pelton, Nova Scotia, Boghead, Wigan, Rochsoles, and similar gas coals. All the varieties of coal may therefore be classed into

I. Coal substances whose sections are for the most part opaque, and abounding in black matter of the purest kind, including the steam, coking, household, and anthracite coals. (Compare Plate B.)

The coals from the low and high main seams of Newcastle, Carr's steam coal, and Cowen's coking coal, may be particularly

noticed as of the purest black description, and perfectly opaque in the thinnest slices. The coal of the Hutton Seam, a sample from Mr. Clark of Walker Colliery, the Ebbvale steam coal, the coking and anthracite coal of Pyle, Glamorganshire, and the household coal of Rhymney, belong to the same microscopic class.

II. Coals more or less transparent, comprehending

1. Gas coals with a clear shining lustre, brittle and crystalline, as Nova Scotia, Pelton, &c.
2. Cannels, as Peace's Wigan, Cowen's cannel, Lesmahago, &c.
3. Coal variously stratified with earthy and black opaque coaly matter, such as splint.

III. Brown coals, or lignites, bovey, jet, &c.

Perhaps there is no fact more strongly brought out by recent investigations, than the impossibility of comparing specimens of coal from the above classes with each other. Thus, for example, the common domestic coals are so black and opaque that it is impossible to make out any structure to which a reference could be made as characteristic of the class; in Cowen's Garesfield coal no yellow matter can be distinguished, while in that from Marley Hill the texture is a homogeneous mixture of yellow and black particles; but no transparent section can be made, and the above observation results from an examination of the powder and edge of the specimen. The only specimen of this class which presented any evidence of vegetable remains was Cowen's coking coal already mentioned. The structure seemed to present transverse sections of woody fibre. It was characterised by clear white regular spaces, with very dark bounding walls imbedded in a very dark molecular matrix, perfectly opaque. The arrangement of the preserved tissue was in a direction oblique to the stratification of the coaly substance. The general conclusion is, that coal, according to the class examined, has a structure peculiar to itself, but that coal from the same class does not always present a uniform appearance in the mass, to the naked eye, as remains of fibres or forms of plants are sometimes found enclosed in its substance.

Among the early investigators of coal, no one has paid more attention to this part of the subject than Goepert, who regards coal with a well-preserved structure as imperfectly mineralised, or not perfectly transformed into coal; a conclusion supported in some

measure by Witham, and confirming our remarks. This view is also adopted by Binney, than whom we have not a more experienced practical geologist, who states that he has only once seen the vascular system perfectly preserved with iron pyrites in a specimen of the *King* coal of Wigan.

The wood-like tissue seen in the coal-seams exactly resembles charcoal: it is termed "mother-" or "father-coal" by the Germans. If the coal is highly bituminous, it is so rapidly consumed that all appearance of texture is destroyed; but specimens may be prepared for examination by the microscope in the following manner, as proposed by Drs. Fr. Schulz and Ehrenberg:—

"A piece of coal about two inches square is to be taken and broken into about 12 pieces of nearly the same size, and treated with nitric acid in a platinum crucible. The nitric acid is to be evaporated at a moderate heat, and the residue ignited till no farther empyreumatic vapours are given off: treat the residue again with nitric acid, and repeat the ignition.

"Thus prepared let the coal be placed in a platinum crucible, with a lid perforated in the centre, and blow air from a gasometer through the aperture in the lid, while the crucible is kept at a red heat over a spirit-lamp.

"The object of this is that the combustion of the coal may be as slow as possible. The ash obtained ought not to cake, but should form a brownish powder. Some white splinters occur among this ash, which appear, on microscopic examination, to be aggregated siliceous cells, arranged in regular succession, and of the structure of the prosenchymatous cells of wood."

As regards the ashes of the coaly substance, the observations of Lyell, Bailey, Hooker, Goepert, and others, show how difficult it is to see remains of vegetable structure in them, even when carefully prepared, and selected pieces taken and decarbonised by the aid of nitric acid and heat.

Sir C. Lyell has noticed organic structure in the coal of Eastern Virginia, which he considers to have been derived from the vegetation of the ancient carboniferous period. Dr. Hooker examined some charcoal-like portions of this coal, and found a total absence of cellular and scalariform tissue, and thought that the structure was not referable to ferns. He found a fibrous texture, but the prominent glands were much more minute than those of coniferous wood, while the large perforated tubes were foreign

to that order. The tissues consisted of parallel fibres or elongated cells, among which were very large tubes whose walls were pierced with circular or longitudinally or transversely elongated holes, either scattered or placed closely together.

The conflicting statements in a recent trial lead to the same conclusion,—that coal, as such, does not in its general structure show appearances of vegetable structure to the naked eye or the microscope.

The microscopic tissues found preserved in the substance of coal consist of portions of vascular tissue, such as woody fibres or scalariform tissue, with cellular tissue of various kinds,—portions of the organs of reproduction, such as seeds of plants of a microscopic size, like the spores or minute seeds of ferns.

Dr. Aitken was the first to detect the spores of ferns in the substance of coal, and has found them in clusters in Boghead, Capeldrae, and other coal.

In Class II. the Nova Scotia and Pelton coals are both amorphous or homogeneous in their thinnest sections, but the granular black matter exists in a greater proportion in the latter. The yellow matter of the Nova Scotia coal is soluble in ether, and slightly so in turpentine and nitric acid. The solution proceeds very gradually, and leaves the black matter unchanged. The same action takes place in the Pelton coal, but much more rapidly, and a portion of its yellow matter is soluble in water. These features are, however, more strongly developed in the cannel coals, and were first noticed by Mr. Hutton, who described them to the London Geological Society in 1832-33. The cells or spaces which he noticed and attributed to the distension produced by gas confined in a somewhat yielding material, are generally of a yellow resinous-like aspect, and may be described as areolar, while the black matter forms as it were the skeleton or net-work of the coal. These areolar spaces hold a definite relation to the stratification of the coal, and agree generally with what we know of stratified rocks. This is so characteristic of cannel and splint coals, that they may be described microscopically as "stratified coals."

The greater number of coal-beds exhibit cleavages which take place in two constant directions,—one being parallel, or nearly so, to the plane of stratification, and the other perpendicular, thus forming an acute angle: hence the coals work or break in masses of a cubicular rhomboidal form. The distortion and flattening of

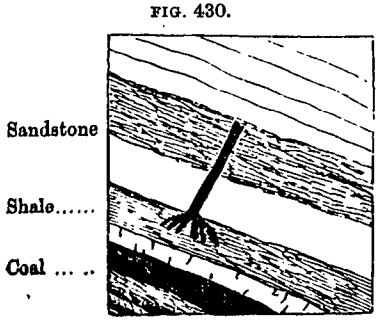
the vegetable remains, and the facility with which the cleavage takes place, has generally some relation to the direction of greatest pressure. The enclosure of the yellow matter in areolar spaces bears, as might be expected, a definite arrangement in the direction of the cleavage. The spaces are flatter and broader as they lie upon the plane of horizontal cleavage, or in the direction of the line of stratification, while they are more elongated in section when examined along the edges of that plane, or along the dip of the cleavage. They vary most in sections taken "across the bed." Messrs. Quekett and Witham describe certain appearances of coal which have led them to regard a section of cannel coal as similar to a section of wood; but Dr. Aitken considers that these are connected with the phenomena of stratification and cleavage.

The stratified appearance seen in cannel and other coals has evidently been produced subsequently to the deposit of the material from which the coal has been produced.

Cracks and seams pass in definite directions through the beds of coals. When the stem of an entire tree, such as a sigillaria, is found erect, the stratified arrangement, as seen in the bed of coal, passes continuously through the substance of the tree when it is coalified, penetrating the stem across the position of its longitudinal fibres. This fact is of great importance in reference to the structure of coal compared with wood, for such an appearance has no similarity to a parallel arrangement of the bundles of woody fibre. Perhaps the most remarkable instance of this kind is that described by Mr. Dawson in the coal measures of Nova Scotia.

In a thick bed of bituminous limestone, and in the midst of Moriday shale, is a very curious collection of upright plants. A tree, converted into coal, springs from the surface of the shale, and passes through 14 feet of sandstone and shale. On the surface of a bed of clay, 8 feet above the main coal, stands another upright tree, converted into hard shining coal, and passes through beds of sandstone and arenaceous shale to a height of 15 feet. Its roots, which are

FIG. 430.



in a state of coal, spread in an irregular manner through the clay. He found very indistinct traces of cellular tissue in the mass, which consisted of compact coal divided by transverse joints, and an immense number of minute vertical cracks, with a few larger fissures which seemed to have a concentric arrangement.

The lignites, &c., in Class III., as shown in the Bovey coal, (see Figs. 2, 3, 4, and 5, Plate B) exhibit a series of gradations from the most perfect ligneous texture to a substance possessing all the characters of cannel coal; the reverse of which is sometimes seen in splint coal, where instances of transition from perfectly preserved wood to ordinary coaly structure occur.

The general and microscopic appearances seen in the lignites, when compared with the cannel coals, and the whole viewed, as it were, in a series, show the actual transition of woody tissue into the coaly substance. In the three hundred specimens of bituminised woods in the German brown coal-fields, Goepert found chiefly coniferæ. The preservation of this species has been explained by supposing that the deciduous-leaved trees had lost their organic connection sooner than the highly resinous wood of the coniferæ, and thus become disintegrated.

The changes through which the vegetable matter has passed in its conversion into coal have evidently been suspended and only imperfectly carried on in the cases of German brown coal, Bovey coal, &c.

We have seen that characteristic microscopic appearances are associated with the predominance of the chemical properties peculiar to the black or carbonaceous, and the yellow, red, or volatile matter; and in the parts where tissue is preserved, as well as more particularly in the lignites, we can see that the tubes or cells have been distended unequally, and even broken up by the increase of yellow or red volatile matter, as is beautifully shown in one of Mr. Quekett's drawings.

The whole range of bitumens,—pure or unmixed, mineral tars, and asphaltum,—have no structure under the microscope, being homogeneous, and clear or brown-coloured.

Geologically, the brown coals or lignites are said to be of more recent formation, and in their varieties, when microscopically examined, the process of transformation is not found to have advanced so far as in cannel coal; but no very definite relation can

be traced between the extent of the process of conversion and the geological antiquity of the species of coal.

In the drawings of the lignites (Plate B), the yellow material invariably occupies the spaces or cavities of cells or vessels, so that their texture becomes expanded, crushed, and broken up, wherever it is found to exist.

The general conclusion confirms the first statement, that *coal is the product of decomposed or otherwise altered vegetable matter, associated with a variable amount of earthy substance, and capable of being used as fuel.**

* For further information upon the microscopic structure of coal, we may refer to the works and monographs of Decandolle, Brogniart, Lindley, Hutton, Hooker, Binney, Karsten, Nicol, Witham, Goepert, Corda, Teschmacher, Bennett, Quekett, Redfern, Greville, Balfour, and Fleming.

FUEL.

Vegetable tissue preserved or uncoalified in the substance of various Coals Matter.

Plate I.

Fig.1.

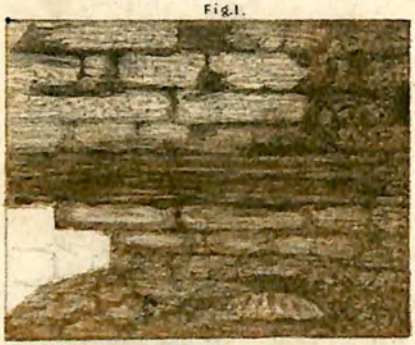


Fig.2

Fig.3

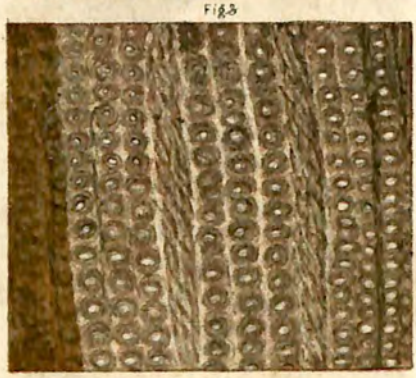


Fig.4

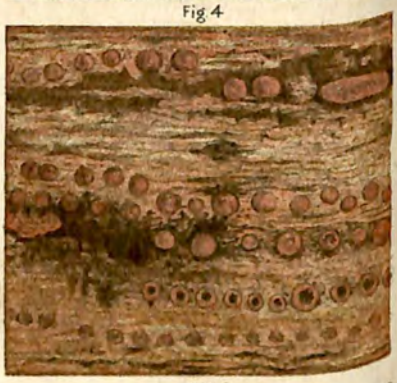
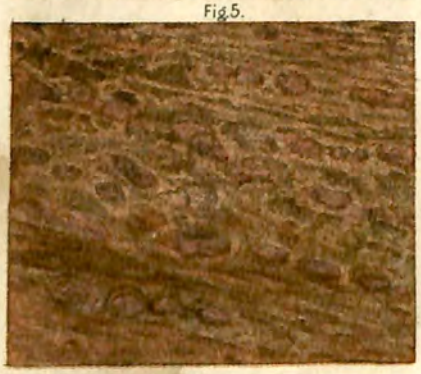


Fig.5.

Fig.6.



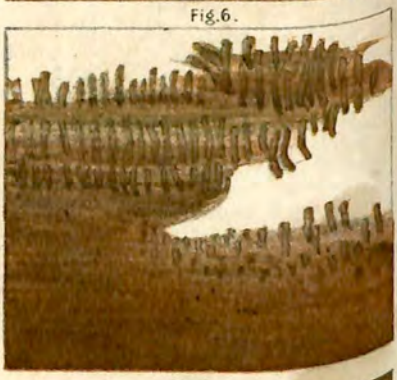


Fig.7.

Fig.8.

Thos. Addis, del. et lith. London & New York, H. Bailliere. 1865. Day & Son, Lith. to the Q...

PLATE A.—(Coloured.)

Fig. 1.—Structure of the more condensed portions of peat, from Allenhead's Moors, ten feet below the surface. It shows the vegetable tissue undergoing the transforming process. Black matter is deposited in and round the boundaries of cell tissue, and in some parts producing perfect opacity. In some places the elongated cells are perfectly distinct and well preserved. At the lower part of the figure a solution, or softened-down-like appearance, marks the nature of the change. A stratified and more condensed lamellar arrangement is seen in the centre of the figure.

Fig. 2.—Horizontal section of the German brown coal, or lignite of the Rhine. The dotted tissue in some parts is distinct, and characteristic of the coniferous woods; in others the dots, glands, or cavities are distended, and are of very various sizes. They are filled with the yellow or brown substance so characteristic of the yellow volatile element in gas-coal. The tissue is altered in this way partly by the distension of these discs or cavities, and partly by the deposit of black matter.

Fig. 3.—Transverse section of the German brown coal or lignite. The woody fibres are cut through by the section transversely to their long axis.

Fig. 4.—Horizontal section of Bovey coal, or English lignite. The vegetable tissue is considerably broken up by the irregular distension of the circular spaces, dots or discs of the coniferous woody tissue, some of which have thus been made into one cavity filled with the yellowish-red substance. The deposit of carbon matter has also commenced, and may be seen filling the centres of some of the discs, and generally the interspaces and walls of the cells and fibres.

Fig. 5.—Transverse section of the Bovey coal, or lignite of England. Irregular distension of the circular spaces by the amber-coloured brown matter. Homologation of the vegetable tissue with the deposit of carbon and yellow matter.

Fig. 6.—Section from Torbane Hill cannel or gas-coal, with preserved or uncoalified vegetable tissue of the scalariform kind. This specimen prepared by Dr. Aitken is in possession of Dr. Balfour, Professor of Botany in Edinburgh.

Fig. 7.—Section of cannel coal from New Battle, in Midlothian, drawn from a specimen cut by the late Mr. Sanderson, of Edinburgh, and now in possession of Mr. Sopwith, of Allenhead. A stripe of uncoalified and tolerably preserved vegetable structure is seen crossing the centre of the section; the upper and lower portion of this stripe have become a homogeneous brown mass, in which no remains of structure can be detected, and towards the uppermost and lowermost parts of the section it gradually passes into the characteristic structure of gas or cannel coal (magnified about 30).

Fig. 8.—Section of cannel coal from A. Pritchard, 102, Fleet Street, London, and now in possession of Mr. Sopwith, Allenhead. The transition state in the process of hystolysis of the vegetable tissue is distinctly traceable; and the preserved or uncoalified vegetation is seen to pass by insensible gradations into the structure of cannel coal.

PLATE B.—(Coloured.)

Fig. 1.—Amorphous or homogeneous gas-coal structure, from the Nova Scotia gas-coal.

Fig. 2.—Amorphous or homogeneous gas-coal substance from Pelton.

Fig. 3.—Horizontal section of Cowan's Newcastle cannel coal, composed of irregular masses of yellow matter amongst opaque carbon-like matter.

Fig. 4.—Longitudinal section of Glasgow splint coal, presenting in some places a minutely stratified appearance, in which large spaces of very irregular forms exist filled with the reddish-yellow matter.

Fig. 5.—Structure of coalified jet from the Wylam Colliery, Durham. It is minutely stratified, but irregular elongated spaces of a convoluted form exist in great abundance, filled with the reddish yellow matter (prepared by the late Mr. Sanderson, and in possession of Mr. Sopwith).

Fig. 6.—Section of cannel coal from the bottom part of the Wigan seam. The appearances were similar in whatever direction the specimen was cut. The bodies resembling spores are seen.

Fig. 7.—Lateral view of a section through the edges of the planes of stratification. A section across these planes was nearly similar.

Fig. 8.—Wigan cannel from the middle part of the seam looking down on the faces of the planes of stratification.

Fig. 9.—Lateral view of a section through the edges of the planes of stratification from the middle part of the seam.

Fig. 10.—Wigan cannel, top part of the seam, looking down on the faces of the planes of stratification.

STRUCTURE OF COAL.

Plate B.

Fig.1.

Fig.2.

Fig.3.

Fig.4.

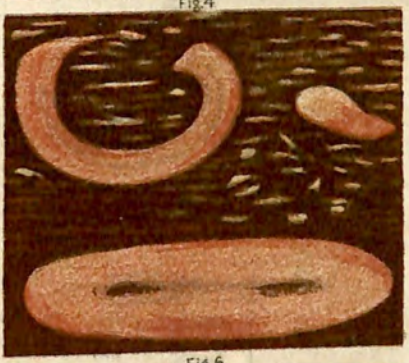


Fig.5.

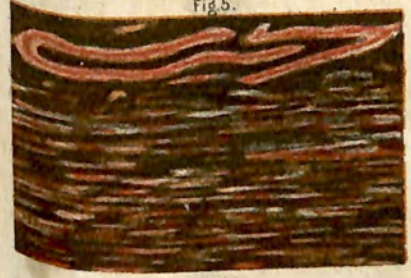


Fig.6.

Fig.7.

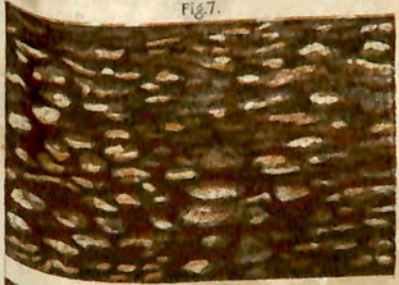
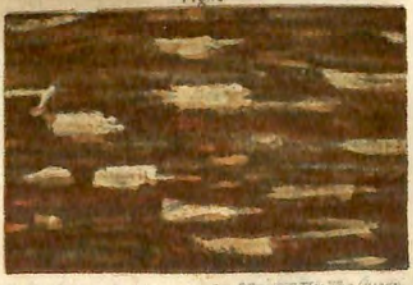


Fig.8.

Fig.9.

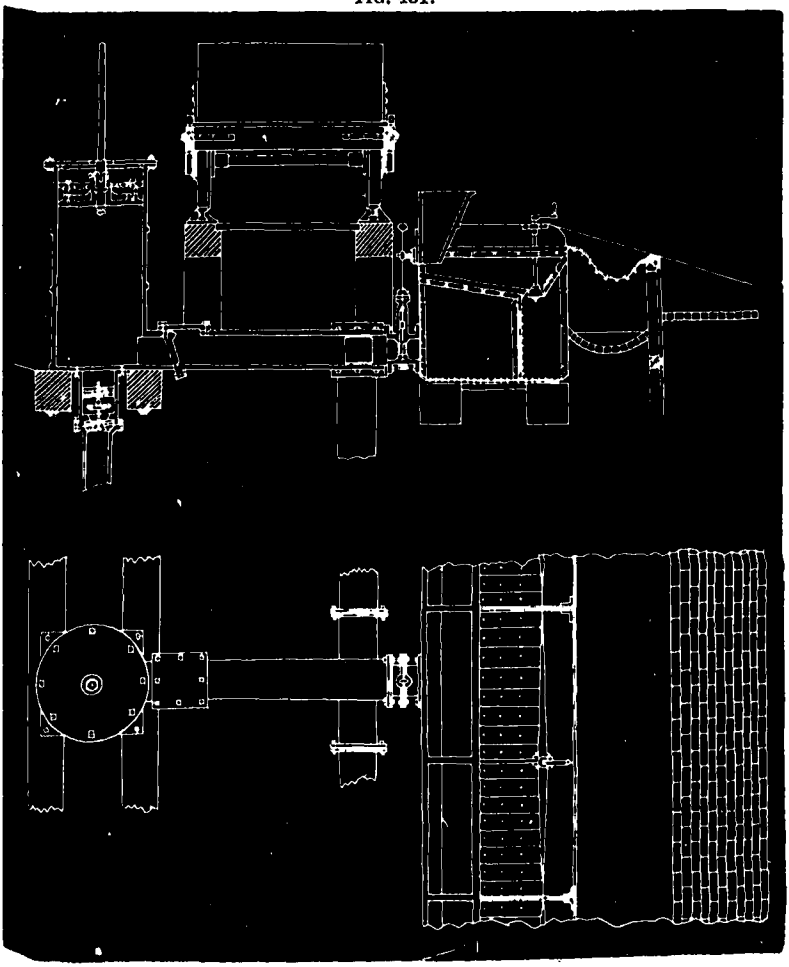
Fig.10.



MEYNIER'S COAL-WASHING MACHINE.

THIS machine consists of a force-pump of large diameter, connected with a chamber of wrought-iron, into which water is forced and made to ascend through a heading of wood pierced with holes, so as by continued movement the cleaner portions of the

FIG. 431.



coal are made to flow to the upper portion of the wrought-iron chamber, and thence over the lip on to a curved drainer (as shown in plan), from whence they are raked on to a paved platform and filled away.

The drainer may be either made of wire gauze, or of perforated iron, supported in its place by iron bars, and the water which goes to the channel below it can flow round the pump and be lifted again if necessary.

Between the force-pump and machine there is a slide valve to regulate the flow of the water, and branch pipes are shown in plan and section by which the other chambers requisite may be supplied in a range of washing-machines.

Between each alternate machine is placed a mitre valve to allow the pyrites and dross to descend into the chamber below it, from whence it can be cleaned out as it accumulates.

The motive power is not shown, but it can be either steam or water.

The cleading ought to be inclined towards the mitre valve, as shown on plan, so as to facilitate the descent of all substances (of superior specific gravity to coal itself) to that point.

About 2 inches from the upper surface of the coal, when the machine is full, iron bars are placed so as to admit of a plank being placed on them, by means of which an operator can reach any part to clean or arrange it during the progress of the work.

The flow of water can be further regulated, in the case of the pump being larger than the requirements, or machines in use, by having an escape valve loaded to such a pressure as to do the work required.

The spouts for feeding the coal ought to be so placed as to cause the coal to pass regularly over the cleading, and subsequently be submitted to the action of the water.

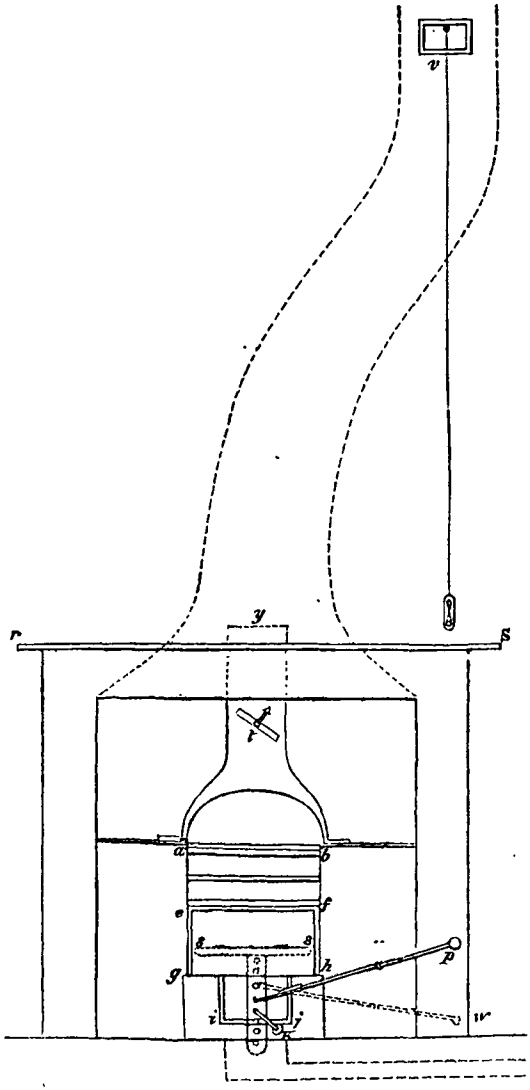
The arrangement as shown is for an ordinary truck, similar to those used in the Midland Counties traffic; but this can be modified according to circumstances.

ARNOTT'S SMOKE-CONSUMING AND FUEL-SAVING FIRE-PLACE.

THE latest improvement in fire-grates, and one which promises to combine the three most essential conditions for domestic comfort and economy, has been presented to the public by Dr. Arnott, the inventor of the stove which bears his name. The prevention of smoke and waste is combined in this contrivance with the efficient warming and ventilation of rooms in a simple and economical manner.

Smoke being caused by the imperfect combustion and cooling of gases containing large quantities of carbon, and which are always

FIG. 432.



evolved when coal is heated to a temperature above 600° F., there is no possibility of preventing its production in a common grate, where fresh coal is being constantly added to the surface of the

red hot coke left from a former charge. The bituminous gases are evolved at the surface, where the fresh coal is heated, and in escaping through it to the chimney are so far cooled that a portion of carbon is invariably separated. Attempts have been made at different times, by Cutler and others, to ignite the coal at the surface of the charge in the grate, and supply it from below: the gases produced from the fresh coal then pass through the red hot coke in escaping to the chimney, and with a properly regulated supply of air must be entirely consumed. This plan, which is obviously correct in principle, has always failed in practice, on account of the complicated nature of the machinery required for raising the supply of coal to the place where it is consumed. Dr. Arnott appears in his plan, however, to have successfully overcome this obstacle. A drawing of the grate is shown in Fig. 432, and represents a common fireplace with mantel- *r s* or chimney-piece, two jambs, and common grate with two bars and bottom, to which four parts, the essentials of the new fireplace, are added. *e f g h* is a box, or receptacle of iron, to contain the charge of coal for the day, with its open mouth placed where the bottom bars of the grate had been. It may either stand on feet on the hearth, or be attached to the grate; besides its fixed bottom *g h*, it is also furnished with a movable one *s s*, like a piston, on which the coal immediately rests, and is raised or lowered with the piston. A piston-rod passes through the fixed bottom, steadied by a guide-hole in the stirrup or bar *i j* below. The piston-rod has notches or openings in it to receive the points of the poker *p o*, which, acting as a lever having its fulcrum in the foot of the box or otherwise, lifts the piston. A catch, or pull, *k* falls into the notches as the piston rises, to prevent its return. No air whatever has access to the bottom of the fuel, the whole supply being derived through the front bars.

In the centre of the bottom front is a door, which may be opened to admit air if wanted, or for removing small coal or ashes which fall past the piston. Where the grate is set low, a small opening is made in the hearth to allow the end of the piston to descend.

A hood or cover *a b y*, like an inverted funnel opened in front, is placed over the fire to contract the open space, receive the products of combustion, and convey them, little diluted with air, into the chimney flue at *y*. This hood may be constructed of

brick or of metal, and in the latter case may be converted into a boiler. A valve or damper *t* is placed in the narrow part of the stalk or the hood to give complete control of the current of air passing through. There is an external index *t*, showing clearly the position of the valve within.

The direction of the chimney-flue in the wall is shown by *y v*, and is generally slanting, to avoid the fireplace of the room immediately above. A ventilating chimney-valve *v* admits air from near the top of the rooms to the flue; this is balanced nearly on its centre of gravity, so that the least pressure from without opens it inwards, but any pressure from within, as of smoke, closes it. There is a wire descending from the valve with a screw or loop-peg for partially or wholly closing it.

Underneath the hearth a flue may be constructed by which fresh air, directly from the atmosphere, can enter the room to be warmed under the fender or near the fire, and then spread in the room: this also has a controlling-valve.

The saving of fuel by this arrangement is very great, one charge of the fire-box, or from 20 to 30 lbs. of coal, sufficing for the entire day, or, indeed, for a much longer period, if, by regulating the supply of air, a very slow combustion is kept up. By means of the ventilator above, and the admission of air by the special channel from without to the part below the hearth, where it can become warmed before entering the room, the most perfect ventilation and a very equable temperature can be maintained.

REVIEW OF THE WHALE FISHERY FOR 1850.

ANNUAL REPORT.

"We present to our readers a full and reliable review of the whale fishery for the last year, as compared with previous years.

By this it will be seen at a glance, that the past has been a year of great prosperity in the trade.

The number of ships returning with full cargoes has been large, while prices have risen to an unprecedented height. Nevertheless, the importation of oil in 1850 will be found to fall short of that of 1849 about 7,000 barrels sperm, and 48,000 whale; and the number of arrivals is less by 6 sperm and 19 right whalers; yet the stock on hand is about the same as on the 1st of January, 1850. This discrepancy, as regards whale oil, is undoubtedly owing to

a diminished consumption, arising from the very high figure at which oil has been held, which has forced many substitutes to the market, and seriously impaired exportations.

The number of vessels employed in the fishery is about the same as that of last year. Of the fleet, 145 have cruised in the Russian and Arctic Seas during the last season with great success; indeed, the average quantity of oil taken is larger than in any previous year. We regret to say that accounts from the sperm whalers in the Pacific are not at all encouraging. The old cruising grounds are pretty well exhausted for the present, and very light catchings are to be expected. If we are to judge by present indications, importations of sperm oil for the coming year will hardly exceed 75,000 barrels, while that of whale oil will not probably fall short of 275,000 barrels. Perhaps no better evidence can be offered of the confidence felt by business men, than the fact that fourteen first-class vessels are in process of construction, or are under contract, all intended for the business, from this district alone, while five or six will be added to the New London fleet.

Ports.	Sperm.	Whale.	Bone.
	barrels.	barrels.	lbs.
New Bedford	39,298	91,627	1,081,500
Fairhaven	8,812	10,559	477,900
Dartmouth	266	7	—
Westport	3,607	324	—
Mattapoisett	2,689	81	—
Tippican	43	1,453	9,300
Wareham	250	2,719	38,100
Holmes Hole	1,208	4,960	56,800
Edgartown	2,164	184	1,700
Nantucket	17,989	1,328	133,000
Yarmouth	68	13	—
Provincetown	3,205	501	—
Boston	3,845	786	3,700
Beverley	368	—	—
Truro	140	—	—
Warren	1,035	—	—
Providence	112	3,368	23,600
Stonington	900	15,226	179,600
Mystic	251	1,588	3,000
New London	2,349	36,545	203,000
Sag Harbor	718	26,498	193,100
Green Port	505	828	4,900
Cold Spring	776	763	—
New York	2,054	1,310	460,000
Orleans	240	—	—
Total in 1850	92,892	200,608	289,200
„ 1849	100,944	248,402	2,281,100
„ 1848	107,976	280,656	2,003,000
„ 1847	120,753	313,150	3,341,680
Average for 10 years	130,721	236,029	2,407,150

Exports of whale oil from New Bradford in 1850:—

To Hamburgh . .	40,617 gallons.
Cowes and a market .	59,874 „

Exports from Boston in 1850:—

	Sperm, barrels.	Whale, barrels.	Bone, lbs.
To England	70,738	26,974	17,475
Scotland	1,600	—	—
Holland	...	...	15,000

Statement of the average prices of sperm and whale oil and whalebone for four years:—

	Sperm.	Whale.	Bone.
1850	120 7/10 cents.	49 9/10 cents.	34 4/10 cents.
1849	108 9/10 „	39 6/10 „	31 6/10 „
1848	100 1/2 „	36 „	30 2/8 „
1847	87 7/8 „	33 „	34 „

Number of ships engaged in the North Pacific Fishery for the last four years, and the average quantity of oil taken:—

	Ships.	Average.	Total.
1847	177	1,059 barrels.	187,443 barrels.
1848	159	1,164 „	185,256 „
1849	155	1,334 „	206,850 „

In 1850, the North Pacific fleet consisted of 145 ships (as nearly as can be now ascertained), 110 of which only have yet been heard from, having taken an average of 1748 barrels this season.

Statement of sperm oil, whale oil, and whalebone on hand in the United States, January 1st, 1851 :—

	Sperm.	Whale.	Bone.
	barrels.	barrels.	lbs.
New Bedford District	2,300	13,812	22,000
Nantucket	750	150	—
Sag Harbor	...	150	70,000
Provincetown	560	—	—
New York	...	...	150,000
January 1st, 1851	3,610	14,062	242,000
1850	3,760	13,000	440,000
1849	10,147	20,936	994,600
1848	5,606	29,126	921,500

Comparative statement of tonnage of vessels employed in the whale fishery on the 1st of January :—

	1850.	1851.
	tons.	tons.
New Bedford	76,858	81,442
Fairhaven	14,735	14,430
Westport	2,817	2,963
Dartmouth	111	111
Mattapoisett	1,760	1,822
Tippican	265	—
Wareham	374	374
Falmouth	1,106	1,106
Holmes Hole	949	949
Edgartown	1,860	1,860
Nantucket	19,732	18,697
Provincetown	1,232	3,095
Quincy	100	—
Beverley	162	326
Lynn	720	720
Yarmouth	90	—
Boston	...	261
Truro	...	143
Orleans	...	115
Somerset	137	—
Warren	4,487	4,669
Providence	842	865
Fall River	646	646
Newport	1,382	1,543
Stonington	5,877	5,391
Greenport	3,059	2,985
New London	15,099	16,586
Sag Harbor	7,935	4,758
Cold Spring	2,878	2,878
New Suffolk	227	227
Mystic	3,384	3,099
Total 1st January	171,484	171,971

Recapitulative table of vessels employed in the whale fishery, January 1st, 1851 :—

Ports.	Ships and Barques.	Brigs.	Schooners.	Tons.
New Bradford	215	3	1	81,442
Fairhaven	45	...	...	14,430
Westport	11	5	...	2,963
Dartmouth	...	1	...	111
Mattapoisett	7	2	...	1,822
Wareham	1	...	...	374
Falmouth	3	...	...	1,106
Holmes Hole	3	...	...	949
Edgartown	5	1	...	1,860
Nantucket	53	1	1	18,697
Provincetown	2	6	19	3,095
Truro	...	1	...	143
Orleans	...	...	1	115
Boston	1	...	...	265
Lynn	2	...	...	720
Beverley	...	2	...	326
Warren	15	...	...	4,669
Providence	2	...	...	865
Fall River	2	...	...	646
Newport	4	...	...	1,543
Stonington	17	...	...	5,391
Mystic	9	...	1	3,009
New London	44	...	4	16,586
Sag Harbor	14	1	...	4,758
Greenport	9	1	...	2,985
Cold Spring	7	...	...	2,878
New Suffolk	1	...	...	227
Total Jan. 1, 1851	502	24	27	171,974
" 1850	410	20	13	171,484

Showing a diminution in the number of ships of 8, and an addition of 4 brigs and 14 schooners during the year; also an increase in the aggregate tonnage of 487 tons.

The estimated annual consumption of the American whaling fleet was 3,845,500 dollars. Value of the annual import of oil and whalebone in a crude state, 7,000,000 dollars, increased by manufacturing to 9,000,000 dollars. The number of vessels in the American whale fishery during the present year, 1849, as gathered from the "Whaleman's Shipping List," is estimated at 610, or 196,113 tons, nearly one-tenth of the navigation of the Union. Receipts of sperm oil the last year, 1848, 107,976 barrels, at an import value of 3,455,232 dollars. Receipts of right whale oil in the same time, 280,656 barrels, at an import value of 3,429,494

dollars; whalebone 2,003,600 lbs., worth 508,762 dollars; crude value of the whole whale fishery in 1848, 7,393,488 dollars.

The average yearly quantity of sperm oil taken for 9 years has been 142,242 barrels; of right whale oil 255,456 barrels; of bone, 2,324,578 pounds. Average yearly value for 9 years, 8,098,360 dollars. There was a falling off in 1848 from the previous year of 13,000 barrels of sperm, 33,000 barrels of right whale, and 1,000,000 pounds of bone; 18 years ago it was estimated, by taking into account all the investments connected with the American whale fishery, that property to the amount of 70,000,000 dollars was involved in it, and that 70,000 persons derived from it their chief subsistence; a valuation which should be much augmented rather than diminished at the present time: the New Bedford district now supplies to the whale fishery 102,305 tons; all other ports, including 66 ships, or 23,000 tons from Nantucket, give 930,808; in all 196,113 tons. The exports of oil to foreign ports in 1848, from New Bedford, was 17,093 barrels."

DETECTION OF SULPHURETTED HYDROGEN AND BISULPHIDE OF CARBON IN COAL-GAS.

The following account of "A quick approximative method of estimating the sulphuretted hydrogen, and bisulphide of carbon in coal gas, by Thornton J. Herapath," is extracted from "The Chemist."

"A simple and exact method of estimating the sulphuretted hydrogen and sulphide of carbon contained in coal-gas has long been considered a great desideratum by chemists.

The process I am about to describe will, I hope, in some measure, supply this want. The reagents and apparatus I employ are:—

1. A weak aqueous solution of caustic potash.
2. A strong alcoholic solution of caustic potash.
3. A solution of the nitrate or acetate of lead.
4. A standard solution of lead, containing one, two, or three one-hundredths of a grain of metallic lead, as nitrate or acetate, in 100 or 1,000 water-grain measures of solution.

5. A standard meter, such as is generally used for testing the illuminating quality of coal-gas.

6. Two Liebig's triangles, and

7. Three graduated tubes or colorimeters of uniform bore. The aqueous solution of potash, I may observe, is used to absorb the sulphuretted hydrogen, whilst the alcoholic solution of potash is afterwards employed to dissolve the bisulphide of carbon vapour, which it converts into xanthate of potash, a salt decomposable by heat into sulphide of potassium, hydrosulphuric acid, &c. as shown by the equation :—

$$C_4H_5KO_2 2CS_2 + 2HO = CO_2 + HS + CS_2 + KS + C_4H_6O_2$$

In testing a gas by this process I proceed as follows:—The two Liebig's triangles having been properly filled, the one with the aqueous, and the other with the alcoholic solution of caustic potash, they are connected together by a piece of sheet caoutchouc in the usual way, and attached to the exit pipe of the standard meter, care being taken to place the one containing the aqueous solution next to the exit pipe. A known quantity, say 10, 20, or 30 cubic feet of the gas to be examined is then slowly transmitted through the triangles; the apparatus is disconnected, and the contents of the triangles are separately poured into two different colorimeters. The solutions are next diluted with a little distilled water, mixed with a few drops of a solution of lead, and the *alcoholic* solution is heated to the boiling point, or until no further darkening in colour ensues. The caustic alkali of both solutions is then supersaturated either with acetic or very dilute nitric acid, and water is added to dilute to the required degree. As the sulphide of lead produced by the decomposition of the xanthate of potash that was contained in the alcoholic solution is generally, if not always, much less in quantity than that produced by the sulphuretted hydrogen absorbed by the aqueous solution of potash, it is advisable to dilute the former with less water. The depth of tint communicated to the fluid by the suspended sulphide of lead in the alcoholic solution is then compared with that produced by adding the standard solution of lead, drop by drop, from a graduated tube, into a third colorimeter, which is filled nearly up to the same mark with distilled water, mixed with a few drops of pure acetic acid, and of a solution of sulphuretted hydrogen. So soon as the tints correspond, the measure of the solutions in the two colorimeters is accurately adjusted by adding a little more water either to the one or the other;

a little more of the standard solution of lead is added, if requisite, to the trial colorimeter, and the number of measures of the standard solution that have been taken is carefully noted. The operation is then repeated with the contents of the other colorimeter containing the sulphide of lead from the *aqueous* solution of potash; and the number of measures of the standard solution of lead taken is again read off. By a simple calculation, we then estimate the relative proportions of bisulphide of carbon and sulphuretted hydrogen, by weight, contained in the gas examined.

For example, let *a* represent the quantity by weight of bisulphide of carbon which is equivalent to the lead contained in 1000 grain measures of the standard solution of lead; *b*, the quantity of sulphuretted hydrogen equivalent to the lead contained in the same bulk of the standard solution; *c*, the number of measures of this standard solution taken as before explained to produce a tint equal in intensity to that of the sulphide of lead in the *alcoholic* solution; and *d*, the number of measures of the same solution by the aqueous solution. Then the proportion by weight of sulphide of carbon and sulphuretted hydrogen contained in the number of cubic feet of gas operated upon is obtained in the following equations:—

$$\text{Bisulphide of carbon} = \frac{c+a}{1000} + 2 \text{ (nearly)}$$

$$\text{Sulphuretted hydrogen} = \frac{d+a}{1000}$$

And as 100 cubic inches of bisulphide of carbon vapour and sulphuretted hydrogen weigh respectively at 60° F. and 30 inches of Bar., 81.8167 and 36.331 grains, the result of the above calculation will afford us the means of ascertaining the proportion of these two substances by volume."

COAL-GAS.

We are indebted to the able editor of the Journal of Gas-lighting for some corrections of the foregoing sheets, and the following additions:—

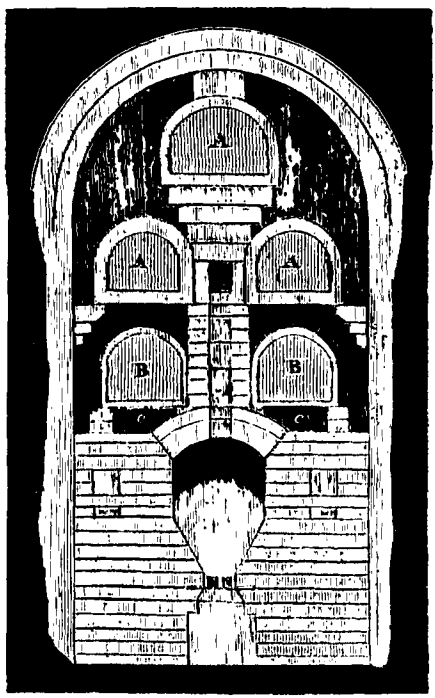
Mr. Barlow informs us (June 4, 1855) that the consumption of coal in the metropolis during 1854, for the production of gas, exceeded 500,000 tons, which would yield 4,500,000,000 cubic

feet, while the income arising from its sale amounted to nearly £1,000,000.

He remarks that the results which are given in tables at page 576 are greater in several cases than those obtained in gas works, the experiments upon which they are based having been conducted on too small a scale for practically testing the coals.

Fig. 433 shows an oven constructed upon a combined system of clay and iron retorts, which was successfully adopted by Mr. Lowe in 1844 at the Chartered Gas Works, Brick Lane,

FIG. 433.



and is extensively used there up to the present day. A A A are three clay retorts which receive the first heat of the furnace; B B are two iron ones, over which the heat traverses before it reaches the exit flues C C. When Newcastle coal is used, the consumption of fuel upon this system is stated not to exceed 25 per cent of the coke produced. The arrangement shown at

page 597 was first constructed by Mr. Croll, under licence from Mr. Lowe.

We are also glad here to give Mr. Methuen the credit of the system of long clay retorts fed at both ends, described at page 600, he having been the first to introduce it at the Commercial Gas Works, Stepney.

In 1851, Messrs. Barlow and Gore obtained a patent for condensing the excess of steam held in suspense by the water gas on its passage from the retorts in which it was generated, before it was admitted into the retorts in which carbonaceous matter was undergoing decomposition for the purpose of rendering it luminiferous. The objects of this process are stated to be the preservation of the carbo-hydrogens which are injuriously acted upon by watery vapour, and the diminution of the production of carbonic acid.

The following table, extracted from a paper containing some experiments by Mr. Barlow on the "Comparative value of coals for the manufacture of gas,"* may be found useful, especially to persons who are compelled to use cannel coal for enriching gas of low illuminating power.

Name of coal.	Number of experiments the average of which is taken.	Produce of one ton of coal.				Equivalent of one cubic foot of gas in grains of sperm.	Consumpt of gas per hour to give a light equal to 12 standard candles.	Value of the gas from one ton of coals in lbs. of sperm.
		Cubic feet of gas.	lbs. of coke.	lbs. of tar.	lbs. of ammoniacal liquor.			
Boghead cannel	3	13,334	715	733.3	none.	1109.	1.3	2,057
Newcastle cannel	3	9,833	1426	98.3	60.	606.	2.37	851
Wigan cannel (Ince Hall)	3	10,850	1332	248.3	161.6	465.8	3.09	718
Lochgelly cannel	2	8,331	1245	225.	340.	439.	3.28	522
Mixture of $\frac{7}{8}$ Lochgelly, $\frac{1}{8}$ Boghead	1	9,055	1200	400.	170.	695.	2.07	899
Ditto $\frac{9}{10}$ Lochgelly, $\frac{1}{10}$ Boghead	2	9,050	1205	335.	290.	600.	2.4	774
Ditto $\frac{11}{12}$ Lochgelly, $\frac{1}{12}$ Boghead	1	9,750	1240	227.	270.	443.	3.25	617
Pelton Main	4	9,500	1540	112.5	112.5	311.	4.7	422
Mixture of $\frac{3}{4}$ Pelton ... $\frac{1}{4}$ Boghead	3	12,800	1366	206.6	116.6	553.	2.6	1,009

Mr. Barlow is of opinion that coals which contain more than 30 per cent of volatile matter require a higher temperature for their distillation.

* Journal of Gas-lighting, April and June, 1851.

Mr. Barlow has kindly revised our sheets on the hydrocarbon gas, and informs us that the oxide of iron in the experiments alluded to at page 641 had the disadvantage of slightly acting upon the heavy hydrocarbons, but not to the extent we mention at page 642. He also adds to our remark on Gillard's process, that the necessity of maintaining a uniform pressure at the burner equal to a column of water 3 inches high, presented insuperable difficulties to the economic distribution of the gas.

In the paragraph describing Mr. Leslie's burner, Mr. Barlow remarks that the slightest excess of pressure, or an undue supply of air, is attended with an imperfect combustion, or the production of smoke, in this kind of burner.

ANALYTICAL TABLES.

ANALYTICAL TABLES.

FAT, BITUMINOUS COALS OF ENGLAND AND SCOTLAND.

Description and Locality of Veins.	By whom analysed and described.	Specific gravity.	Analysis of 100 parts of coal.		
			Carbon.	Bitumen, volatile matter and water.	Ashes and cinders.
Alfreton, furnace coal	D. Mushet	1.235	53.46	45.50	2.04
Butterley „ Derbyshire	„	1.264	52.88	42.83	4.29
Derbyshire, cannel coal, Alfreton	„	1.278	48.36	47.00	4.64
Wigan, cannel coal	Dr. Thomson	....	52.60	44.00	3.40
„ „	Kerwan	1.272	75.20	21.68	3.10
„ „	R. C. T.	1.275	61.73	—	—
Lancashire, cannel coal	Dunn	....	56.40	41.00	2.60
Woodhall, near Glasgow, cannel coal	Dr. Ure	1.228	—	—	—
Liverpool coal	Johnson	1.260	54.90	40.48	4.62

FAT, BITUMINOUS ADHESIVE COAL, COKED PREVIOUSLY TO USING IN THE FURNACE.

Description and Locality of Veins.	By whom analysed and described.	Specific gravity.	Analysis of 100 parts of coal.		
			Carbon.	Bitumen, volatile matter and water.	Ashes and cinders.
Newcastle-upon-Tyne, Birtley Works	Dufrenoy and Berthier	1.270	60.50	35.50	4.00
„ „	Thomson	....	65.90	32.60	1.50
„ „	Karsten	1.256	67.65	31.50	0.85
Northumberland, Tyne Works	Dufrenoy and Berthier	....	67.50	30.00	2.50
Staffordshire, Apdale Works	„ „	....	62.40	34.10	3.50
Redesale, Newcastle, N. of Tyne	Richardson	....	49.95	51 00	3.05
Wylam	„	....	48.49	37.60	13.91
Garesfield and Auckland	„	....	72.71	25.90	1.39
Newcastle coal (mean)	W. R. Johnson	1.257	57.00	37.60	5.40

BITUMINOUS COAL, USED CRUDE IN THE HOT AIR FURNACE.

Description and Locality of Veins.	By whom analysed and described.	Analysis of 100 parts of coal.		
		Carbon.	Bitumen, volatile matter and water.	Ashes and cinders.
Staffordshire, Tipton, Wednesbury coal works	Berthier	67.50	30.00	2.50
Derbyshire, Butterley, cherry coal	„	57.00	40.00	3.00
Derbyshire, Dodnor Park, soft coal	„	51.50	45.50	3.00
Soft or mixed English	D. Mushet	53.00	—	—

BITUMINOUS AND SEMI-BITUMINOUS COALS OF SOUTH WALES, ON THE EASTERN SIDE OF THE COAL BASIN.

Description and Locality of Coal Beds.		Thickness of each bed.	Analysis of 100 pts. of coal by Mushet. Carbon.	Bitumen, volatile matter, &c.	Ashes or cinders.	The Coal described, and its uses.
		ft. in.				
Abersychan ..	Meadow vein	8 6	65.98	29.40	4.62	thin laminæ, furnaces.
	Old coal	2 6	71.10	27.40	2.50	laminæ ,,
Golynos Iron works	Three quarter	5 6	71.88	25.50	2.62	,, ,,
	Rock vein	7 0	69.60	27.40	3.00	thin laminæ, run out fires.
	Meadow vein	7 0	68.00	27.50	4.53	dense, furnaces.
	Old coal	2 4	73.40	20.60	6.00	laminæ ,,
Verteg Iron works. Furnace coal	Red vein	4 0	69.45	26.30	4.25	,, ,,
	Big vein	4 0	66.05	30.70	3.25	irreg'ly laminated, furnaces.
	Droydeg or rock vein ..	4 0	64.45	32.30	3.25	oblong, forge and mill.
	Three quarter	5 6	67.90	29.60	2.50	rather friable, furnace.
	Meadow vein	7 0	69.25	30.50	9.25	thin laminæ ,,
Blaenafon Iron works	Three quarter	5 6	65.63	31.25	3.12	,, ,,
	Droydeg or rock vein ..	5 6	65.55	28.95	5.50	cubical, refineries.
	Meadow vein	2 10	72.00	26.00	2.00	,, furnace.
	Old coal	6 0	75.21	22.29	2.50	laminated ,,
Clydach or Llanelly Iron works	Red vein	3 0	76.58	20.80	1.62	,, forge and mill.
	Big vein	5 0	73.42	24.58	2.00	thin layers ,,
	Three quarter	2 9	72.70	25.30	2.00	broad ,,
	Droydeg or rock vein ..	7 0	72.13	21.87	6.00	cubical ,,
	Tach coal	3 0	70.05	25.57	4.38	cones, household.
	Yard Vein	2 9	78.68	19.32	2.00	hard, furnaces.
	Old coal	5 6	77.55	18.95	3.50	alternating laminæ, furn'ces
Nant-y-glo Iron works	Elled coal	3 6	81.87	17.13	1.00	lamellar ,,
	Three quarter	..	82.65	15 10	2.25	coking, for the refineries.
	Droydeg vein	..	77.14	17.86	5.00	twisted, forges and mills.
	Old coal	5 6	78.75	18.75	2.50	imperfect, furnaces.
Sirhowey Iron works	Ell coal	..	82.04	16.71	1.25	sectional ,,
	Three quarter	..	83.50	12.00	4.30	with numerous partings.
	Big vein	8 0	81.52	15.10	3.38	rhomboidal, furnace.
	Mudelog vein or droydeg	..	80.50	11.87	7.63	partially granulated.
	Yard coal	..	82.24	15.88	1.88	twisted, with clod.
	Engine coal	4 0	82.46	15.41	2.13	irregul'y granular, furnaces.
	Three quarter engine ..	..	75.78	13.22	11.00	hard.
	Old coal	4 0	78.50	13.00	8.50	conchoidal partings.
Ebbw Vale Iron works	Yard coal	3 2	81.04	15.83	3.13	friable, forges and mills.
	Three quarter	3 0	80.25	17.00	2.75	cubical, blast furnaces.
	Big vein	4 8	81.37	17.00	1.63	,, ,, and forges.
	Bydelog or droydeg	2 10	72.88	16.87	10.25	coarse ,, ,,
	Ell coal	3 2	82.32	16.30	1.38	granular ,, ,,
	Old coal, top / ,, bottom	5 6	79.28 / 81.77	18.22 / 15.73	2.50	cubical, force and mill.
Beaufort	Old coal	4 6	76.82	20.80	2.38	cubical, furnace and refinery
Pont-y-mister	Forge coal	..	75.06	22.22	2.72	,, ,, forge.
Blaina	Big vein	5 6	72.14	25.86	2.00	granular ,, ,,
	Three quarter	5 6	77.38	21.12	1.50	cubical ,, ,,
Tredegar Iron works	Big vein, top	3 0	80.45	16.55	3.00	compact, blast furnace.
	,, lower part	3 0	81.56	14.94	3.50	very compact ,,
	Red vein, upper part ..	1 0	79.44	14.06	6.50	laminated.
	,, under part ..	3 0	80.26	18.49	1.25	reedy laminæ, blast furnace.
	Bydelog (droydeg)	3 0	78.90	17.97	3.13	fine laminæ, forge.
	Yard vein	..	83.26	15.36	2.38	reedy laminæ, blast furnace.
	Penmark vein	..	80.11	14.06	5.83	reedy, forges and mills.
	Three quarter	..	80.20	13.80	6.00	laminæ with clod.
	Engine coal, or old coal	5 6	77.30	15.20	7.50	reedy.
Rhymney Iron works	Big vein, upper part	..	81.26	16.24	2.50	partially reedy, blast furnace
	,, lower part	..	82.33	13.17	4.50	strong ,,
	Raslas vein	7 0	82.79	12.96	4.25	reedy ,,
	Brassy vein	1 3	83.38	14.37	2.25	twisted, workmen's fires.
	Red coal	3 6	84.25	12.75	3.00	granular, furnaces.
	Yard coal	..	80.92	16.20	2.88	irregular ,,
	Four feet coal	..	80.15	15.10	4.75	irreg. laminæ, forges & mills
	Fire clay coal	1 0	80.60	17.40	2.00	reedy.
	Black vein	2 6	82.51	14.99	3.50	,, forge.

SEMI-BITUMINOUS OR STEAM COALS OF SOUTH WALES.

Description and Locality of Coal Beds.		Thickness of each vein.	Analysis of 100 pts. of coal by Mushet. Carbon.	Bitumen, volatile matter, &c.	Ashes or cinders.	The Coal described, and its uses.
		ft. in.				
Bute Iron works	Red vein	4 0	83.04	14.58	2.38	thin laminæ.
	Big vein	9 0	83.53	13.74	2.73	„
	Raslas vein	9 0	84.06	12.44	3.50	„
	Four feet vein	4 0	78.30	16.45	5.25	in compact, forges.
Dowlais Iron works	Big vein, upper part	11 0	80.88	15.62	3.50	ready, blast furnaces.
	Middle part		85.00	11.87	3.13	thin layers, brittle.
	Bottom part		82.81	13.44	3.75	irregular, shining.
	Raslas vein, upper part	9 0	84.08	13.02	2.90	imperfect, cleavage.
	Lower part		85.02	13.23	1 75	strong, laminæ thin.
	Upper four feet	4 0	85.75	12.75	1.50	prisms, furnace coal.
	Lower four feet	4 0	85.35	12.40	2.25	shining laminæ.
	Cwmcenol	2 9	88.63	9.74	1.63	in layers, furnace coal.
	Four feet forge	5 0	88.78	7.97	3.25	part reedy, forge coal.
	Little vein	3 0	86.90	11.72	1.38	thin laminæ, forges.
‡Pen-y-darren Iron works	Foes-y-frane	7 0	85.04	11.46	3.50	compact, blast furnaces.
	Raslas	7 0	87.69	10.31	2.00	incompact „
	Three feet coal	3 0	85.07	12.18	2.75	broad „
	Four feet coal	4 0	88.50	10.00	1.50	hard „
	Upper vein	3 6	86.08	10.42	3.50	„ forges and mills.
	Roof-pin vein	2 0	83.30	11.20	5.50	„ mixed quality.
	Big vein	..	86.01	12.24	1.75	crystallised, with clod.
	Bottom coal	4 0	87.20	11.30	1.50	compact, forges.
*Plymouth & Duffryn Iron works	Upper or yard coal	3 9	79.06	15.34	5.60	mixed „
	Four feet coal	4 0	84.98	11.77	3.25	„ less shining.
	Clynmil coal, top part	3 6	86.62	12.00	1.38	conical, best furnace coal.
	Bottom part	4 6	85.48	12.39	2.13	granular, blast furnaces.
	Raslas, top part	4 6	82.05	13.95	4.00	bright „
	Bottom part	3 6	83.84	13.33	2.83	both reedy and granular.
	Upper Dingle coal	3 6	77.00	20.00	3.00	broad, forges and mills.
	Lower Dingle	2 6	80.34	16.66	3.00	less bright and shining
*Cyfarthfa and Ynnis Vach. Merthyr Iron works	Cyfarthfa big vein	9 0	90.28	7.97	1.75	slightly reedy.
	Cwm-dhu pit	6 0	88.78	9.22	2.00	regularly laminated.
	Cwm-mynedd	5 6	88.87	9.00	2.13	slaty, forges and mills.
	Cwm-y-glo	4 0	89.29	6.58	4.13	incompact, blast furnaces.
	Upper yard vein	3 0	86.80	11.20	2.00	regular „
	Gelly-deg	3 0	91.86	6.14	2.00	specular, forges.
	Mountain vein	3 6	90.02	8.48	1.50	crystallised, furnaces.
	„ ironstone	1 6	92.11	6.14	1.75	reedy, granular.
Aberdare Iron works	Four feet coal	4 0	87.00	11.50	1.50	compact, blast furnaces.
	Raslas vein	10 0	88.89	9.11	2.00	„ forges.
	Two feet coal	2 0	88.12	10.00	1.88	mixed reedy and granular.
	Small vein	5 6	80.42	10.83	8.75	compact, refineries.
	Foes-y-frane	4 0	84.67	8.33	7.00	„ furnaces.
	Two feet 9 inch coal	2 9	88.51	9.99	1.50	bright reedy coal.
	Yard vein	..	82.99	14.26	2.75	reedy, furnaces.
	Black mine coal	..	91.18	6.82	2.00	bright reeded coal.
	Upper vein	..	82.12	12.13	5.75	granular, with clod.
Hirwain Iron works	Big vein	9 0	88.94	7.18	3.88	crystallised, forges.
	Four feet coal, or Glowynn	4 0	90.26	7.86	1.88	slightly reedy, furnaces.
	Six feet coal	6 0	82.96	8.04	2.06	regular reeded, forges.
	Pit vein	3 0	87.15	8.85	4.00	reedy and granular.
†Argoed in Cwm Buchan	Upper vein	3 0	76.54	22.50	0.95	friable, weak.
	Lower vein	3 0	74.30	23.40	2.30	harder, more compact.
†Oakwood, Glamorganshire, second coal series	Wern Dhu	2 3	78.02	20.18	1.80	used for smelting iron.
	Wern Pistill	2 6	80.06	17.46	2.48	hard, compact.
	Rider vein	..	80.67	18.52	0.81	second coal series.
	Tor Mynydd	1 8	81.18	18.00	0.82	„ „
†Cwm Buchan third coal series	Four feet, upper vein	4 0	91 67	7.70	0.63	strong, heavy coal.
	„ lower part	4 0	88.65	10.00	1.35	reedy, furnaces.
	Nine feet coal	9 0	83.74	15.20	1.06	large and lumpy.
	Yard coal	..	78.90	20.00	1.10	clean and bright.
†Pyle, lower series	Vein fawr, 1	9 0	72.82	24.68	2.50	very bright, reedy coal.
	„ 2	9 0	72.58	24.42	3.00	cannel & bituminous mixed.

* On the Northern side of the Coal Basin. † South side of the Coal Basin.

BITUMINOUS AND SEMI-BITUMINOUS OR STEAM COALS OF SOUTH WALES, ON THE SOUTH-EASTERN SIDE OF THE COAL BASIN.

Description, Locality, and names of Coal Seams.		Thickness of each vein.	Analysis of 100 pts. of coal by Mushet			The Coal described, and its uses.
			Carbon.	Bitumen, volatile matter, &c.	Ashes or cinders.	
		ft. in.				
Mynyddys-wyn vein, sale coals for household purposes, Upper or red ash coals.	Cyfarthfa furnace	..	88.07	8 50	3.43	irregular crystallised.
	Powell's	4 0	66.58	27.92	5.50	cubical, compact, reedy.
	Morrison's	4 0	68.58	26.92	4.50	,, ,,
	Penner vein	4 0	60.25	33.00	6.75	slightly granular, reedy.
	Cwm Dows (Morrison)	3 4	68.86	27.14	4.00	cubical.
	Prothero's	4 0	64.95	33.30	1.75	,, compact.
	Rosser Williams	4 0	68.50	30.00	1.50	no sulphur, clean.
	Crossfield's	..	69.34	24.16	6.50	cubical, compact.
Beddws vein, Lower red ash coal	Cwm Tillery	2 4	64.45	24.80	10.75	shining bright.
	Phelps's	2 4	68.00	30.00	2.00	compact, hard, strong.
	Abercarne	2 9	66.88	28.37	4.75	,, cubical, reedy.
	Cwm Carne	2 9	62.63	31.10	6.25	,, ,, ,,
*Risca veins	Upper Rock vein	3 6	66.11	31.14	2.75	for steam-packets.
	Lower Rock vein	3 6	61.78	34.28	3.94	oblong masses, reedy.
	Big vein	12 0	66.02	29.15	2.83	irregular, no sulphur.
	Red vein	..	61.25	33.80	4.95	pyrites, strong.
	Sun vein or Meadow vein	3 0	67.28	31.34	1.38	compact, reedy.
*Cwm Brane coals	Yard vein	2 0	63.03	32.60	4.37	with layers of splint.
	Rock vein	6 0	62.22	34.78	3.00	cubical.
	Red vein	3 6	60.65	31.35	8.00	oblong reedy.
	Meadow vein	5 8	66.34	28.16	5.50	strong, bright, shining.
	Old coal	3 0	68.30	27.70	4.00	cubical, tarnished.
*Blaen-dare furnace coals	Rock vein	10 0	68.86	28.64	2.50	used for blast furnaces.
	Meadow vein	6 0	67.84	29.16	3.00	,, ,,
*Pen Twyn furnace coals	Big vein	4 6	71.88	25.50	2.62	laminæ regular, reedy.
	Droydeg, or Rock vein	3 6	68.20	24.80	7.00	cubical.
	Meadow vein	7 0	63.65	32.60	3.75	cross or sectional, pure.
	Old coal	2 6	68.50	27.50	4.00	incompact, friable.
Abersychan British Iron Company	Red vein	4 8	72.95	25.30	1.75	used raw in blast furnaces.
	Big vein	7 0	67.05	25.70	7.25	,, ,,
	Rock vein	8 0	69.30	25.70	5.00	cubical splint.
†Park, south veins of the South Wales coal basin, between Pyle and Llantrissant	Cribbwr Vach	4 6	72.36	26.14	1.50	bright, furnaces.
	Bedws vein	10 0	70.68	25.82	3.50	,, in thin laminæ.
	Maesteg issa	5 0	79.69	19.26	1.25	,, blast furnaces.
	Llangonydd	5 0	60.40	38.60	1.00	,,
	,, No. 2	2 6	69.64	27.86	2.50	imperfectly rhomboidal.
	,, 20 inch	1 8	70.22	28.28	1.50	broad, reedy coal.
	Hirwain common	4 6	69.34	29.16	1.50	smooth fracture.
	,, 2 yard coal	4 0	73.75	22.50	3.75	slaty, partially reedy.
	Llanharry	6 0	65.75	33.00	1.25	strong, reedy coal.
	Collenna 3 feet	3 0	75.06	23.44	1.50	broad, reedy structure.
	,, cannel coal	3 0	63.25	34.12	2.63	laminated, oolitic.
†Mellin Griffin and Pentyrch, near Cardiff	Little vein	..	70.66	27.34	2.00	workmen's fires.
	Brassey vein	2 4	61.00	30.00	9.00	heavy, forges and mills.
	Pentyrch hard vein	4 0	71.25	23.75	5.00	crystallised, blast furnaces.
	,, forked vein	5 6	64.63	31.87	4.50	reedy, tin plate works.
	,, wing coal	..	—	—	—	—
	pure anthracite	5 0	95.69	2.81	1.50	,, furnace and forge.
Very dry, with excess of carbon in S. Wales	Dowlais iron works	..	79.50	17.50	3.00	lamellar, does not cake.
	Cyfarthva ,,	..	78.40	18.80	2.80	,, cakes.
	Pen-y-daran ,,	..	76.80	20.00	3.20	,, ,,

* The white ash or furnace coals.
† Bituminous coals of South Wales, South side of the Canal Basin.

By the term "reedy coal," is locally understood a coal in which the vegetable impressions are conspicuous and abundant in its substance,—"Clod coal," having a soft, laminated vegetable texture,—"Splint coal," which does not lose its form in coking, angular,—"Semi-bituminous coal coke," where the angles of the cokes are rounded, and having considerable adhesion,—"Partially bituminous," where the coked masses have rounded edges, and slightly adhere together,—"Bituminous cokes," those which dissolve and enter into fusion, forming a compact mass.

ANTHRACITE OF SOUTH WALES, TOWARDS THE WESTERN EXTENSION OF THE BASIN.

Description and Locality of Coal Beds.		Thickness of each veip.		Analysis of 100 pts. of coal by Mushet.			The Coal described, and its uses.
				Carbon.	Bitumen, volatile matter, &c.	Ashes or cinders.	
		ft.	in.				
Pwll-feron, in Neath valley, Neath Abbey furnaces	Pwll feron vein, 1st bed	18	0	89.34	6.66	4.00	mixed with coke.
	,, 2d ,,			86.56	6.94	6.50	very hard and reedy.
	,, 3d ,,			86.24	12.00	1.76	anthracite.
	,, 4th ,,			90.59	8.50	0.91	,,
	,, 5th ,,			91.08	8.00	0.92	more brilliant.
	,, 6th ,,			81.00	9.00	10.00	more reedy.
Yyiscydwn Iron works Swansea	Big vein	..		88.70	7.80	3.50	—
	Brass vein	..		88.70	7.80	3.50	—
	Cwm Phil vein	..		89.60	6.66	3.74	bright and shining.
	Swansea peacock coal	..		89.00	7.50	3.50	surface smooth.
Ystal-y-ferra, Iron works, Swansea valley	Big vein, 1st bed	6	0	91.42	7.08	1.50	blast furnaces.
	,, 2d ,,			92.89	5.61	1.50	flat, boarded coal.
	,, 3d ,,			91.99	6.51	1.50	reedy and granular.
	Cefn vein, upper bed	..		91.26	7.24	1.50	pitchy, bright, shining.
	,, lower part	..		91.89	6.61	1.50	partially granular.
	Brass vein, upper part	..		92.46	6.04	1.50	bright, laminæ irregular.
	,, lower part	..		91.52	6.98	1.50	irregular, reedy.
	Black vein	..		93.14	5.36	1.50	rough, crystallised.
	Little vein	..		90.64	7.86	1.50	regular but twisted.
	Pentyrch wynn	5	0	95.69	2.81	1.50	reedy, forge and furnace.
Cwm Neath	Three feet vein	3	0	94.10	4.90	.93	analysis by D Schafhaeutl.
	Eighteen feet vein	18	0	91.43	6.24	2.28	
	Nine feet vein	9	0	93.12	5.22	1.59	
	Cinderford furnace, or Lower High coal Delf	3	0	62.00	36.00	2.00	strongly reeded, bright.
Bituminous coals of the forest of Dean, Gloucestershire.	Park-end coal	4	0	..	..	..	free from splint.
	Coleford High Delf, top part	4 to	6	63.72	32.03	4.25	thin, bright laminæ.
	Middle part			63.61	34.89	1.50	reedy, bright, pyritous.
	Bottom part	6	0	60.96	37.29	1.75	smooth fractured.
	Churchway coal top	5	0	60.33	35.67	4.00	irregular fracture.
	Churchway coal bottom			64.13	34.74	1.23	smooth, straight, reedy.
	Rocky vein	2	0	61.73	36.14	2.13	strong, partially reedy.
	Starkey coal	2	6	61.53	36.72	1.75	partially reedy.
	Park-end, Little Delf	1	8	58.15	36.35	5.50	compact, bright, reedy.
	,, Smith end	2	0	63.36	34.89	1.75	heavy, compact, reedy.
*Corbyn's Hall	Tow coal, part of the 10 yard coal	..		51.90	40.60	7.50	strong, reedy coal.
	,, ,,	..		56.00	42.50	1.50	irregularly laminated.
	Heathing coal	..		54.17	43.33	2.50	strong, bright, reedy.
	Brooch coal	..		50.49	47.76	1.75	bright, pitchy fracture.
*South Staffordshire	New mine top coal	..		52.77	45.10	2.13	reedy, without splint.
	Fire clay coal	..		51.40	46.35	2.25	weak, friable, reedy.
	New mine bottom coal	..		53.98	44.27	1.75	reedy, mixed with clod.
*Bentley Estate, South Staffordshire	Ten yard coal	..		54.05	42.70	3.25	pitchy, bright coal.
	,, bottom part	..		63.57	34.18	2.25	bright and thin splint.
	Four feet coal	4	0	53.18	44.82	2.00	bright, shining, smooth.
	Three feet coal	3	0	54.82	43.12	2.00	bright, pitchy, reedy.
	Fire clay coal	5	0	54.84	42.91	2.25	strong, reedy, uniform.
	Bottom vein	7	0	62.87	32.00	5.12	hard, splint coal.
	Five feet splint coal	5	0	49.42	45.83	4.75	laminæ minute.
	Bottom coal	..		79.78	10.72	9.50	imperfectly crystallised.
Land end, North Staffordshire	Bassey mine coal	..		58.30	38.70	3.00	reedy, dull surfaced.
	Little mine coal	4	0	62.30	35.20	2.50	compact.
	Great row coal	9	0	57.38	39.74	2.88	smooth, thin laminæ.
	Best furnace coal	10	0	65.20	32.30	2.50	bituminous looking coal.
	Ashes coal	..		61.32	37.18	1.50	bright, shining, cubical.

* Bituminous coals of Staffordshire.

BITUMINOUS COALS OF STAFFORDSHIRE, SHROPSHIRE, NORTH WALES, DERBYSHIRE, AND YORKSHIRE.

	Description and Locality of Coal Veins.	Thickness of each seam.	Analysis of 100 pts. of coal by Mushet. Carbon.	Bitumen, volatile matter, &c.	Ashes or cinders.	The Coal described, and its uses.
		ft. in.				
North Staffordshire. Golden H. Kidsgrove.	Little Row coal	4 0	63.08	34.67	2.25	bright, with clod partings.
	Seven feet coal	7 0	67.90	30.47	1.63	thin layers, furnace.
	Stony vein	8 0	65.17	33.33	1.50	compact.
	Banbury or Harecas	..	63.84	35.16	1.00	bituminous.
	Knowles's coal, Delph Lane	10 0	59.64	37.86	2.50	bright, free burning.
	Peacock coal, Fenton Park	9 0	60.42	37.08	2.50	cubical, furnaces.
	Spendcroft vein	4 0	58.67	39.58	1.75	broad, potteries.
	Ten feet coal	7 0	58.89	39.11	2.00	uniformly reedy, potteries.
	Grent Row coal	8 0	60.80	37.70	1.75	cubical, potteries & salt wks.
	Little Row coal	4 0	62.47	34.53	3.00	hard ,, ,,
Shropshire.	Shropshire stone coal	..	58.17	39.20	2.63	bright, clod partings.
	Sulphur coal	..	55.72	42.03	2.25	broad, for inf. house purposes
	Clod coal	..	63.79	35.58	1.63	reedy, furnaces.
	Randle coal	..	64.19	32.81	3.00	,, ,,
	Flint coal	..	60.63	36.87	2.50	hard, sale or smith's use.
	Top coal	..	64.10	34.77	1.13	regular.
	Best fungous coal	..	63.33	35.67	1.00	minutely lamin. no pyrites.
	Double coal	..	57.87	41.38	.75	hard, blast furnace.
North Wales. Dee Bank. Brymbo Coals.	Three yard coal, part not coked	..	61.31	35.80	2.89	fine ,,
	,, part coked	3 0	62.70	35.70	1.60	strong ,,
	Two yard coal coked	..	69.98	28.60	1.42	bright ,,
	Brassy vein coked	5 6	64.58	34.10	1.32	cubic ,,
	Crank coal	2 6	73.56	25.70	.74	mixed, furnace and sale.
	Drowsall vein	5 0	62.69	36.70	.60	not firm, free.
	Powell vein	5 0	63.41	34.80	1.79	shining.
	Five yard vein, top part	..	61.89	36.20	1.91	laminated, free.
	,, middle	..	62.72	36.00	1.28	more compact, iron making.
	,, bottom	..	63.79	32.85	3.36	thin laminæ, with clod.
	Three yard coal	..	62.88	36.00	1.12	compact, free.
	Two yard coal	..	60.61	38 47	.92	free, shining fracture.
	Bone coal	..	55.20	40.00	4.80	hard, lead works.
North Wales.	Pankey Iron works, stone vein	2 0	61.95	35.67	2.38	broad, partly crystallised.
	Pant Iron works, blast furnace coal	1 7	67.25	31.25	1.50	granular, for blast furnace.
	Coed Talon	9 0	58.50	40.00	1.50	surface ,,
	Sweeny colliery, brassy vein	3 0	49.94	34.56	15.50	alternate layers ,,
	Cefn colliery, near Rhuabon works	7 0	57.49	36.56	6.25	,,
	,, brassy coal	3 0	66.37	32.13	1.60	laminated.
	Black Park coal, 2 yard vein	6 0	57.50	40.00	2.50	firm, with splint.
	,, 1½ yard vein	4 6	59.88	38.12	2.00	strong, with clod.
	Llwyn-y-onnion, ¾ yard coal	..	62.85	34.40	2.75	smooth, reedy, blast furnace
	Chirke bank colliery, strangers coal	5 6	57.00	40.00	3.00	hard.
	Delf colliery, yard vein nr Rhuabon	..	64.89	34.11	1.00	compact.
Derbyshire.	Kirby, upper hard or main coal	6 0	64.15	33.85	2.00	mixed, shining parting.
	Dunshill, near Swanwick	..	55.77	40.73	3.50	strong, breaking oblong.
	Swanwick, main coal	..	60.27	38.23	1.50	,, twisted laminæ.
	Main, upper hard, Duckmanton	..	64.47	32.03	3.50	,, blasted furnaces.
	Normanton Com. Codnor Park co.	..	56.21	41.66	2.13	free, forge and mills.
	Main soft coal	..	56.49	37.76	5.75	,, clod, spar.
	Alfreton works, lower hard coal	4 0	62.60	35.15	2.25	strong, blast furnaces.
	Butterly park colliery ,,	..	61.14	34.11	4.75	splint ,,
	Morely park works ,,	..	55.89	37.86	6.25	,, ,,
	Chesterfield ,,	..	61.65	35.10	3.25	mixed, good cleavage.
	Double or Minge coal	..	60.66	37.34	2.00	bright, furnaces.
	Clod coal	.	61.21	37.29	1.50	smooth fracture.
	Buckland Hollow or Kilburn coal	..	58.62	40.00	1.38	broad, smooth fracture.
	Moreley Park, cannel coal	..	45.00	45.05	9.95	conchoidal.
	Cannel coal near Alfreton works	..	55.27	40.73	4.00	beautiful, specular.
Yorkshire.	Lower Moor, better bed	2 4	67.06	32.19	.75	dense, furnace and forge.
	,, black bed	1 8	71.42	27.08	1.50	friable, domestic use.
	Bowling, better bed	1 10	64.25	32.55	2.06	bituminous, furnace & forge.
	,, crow coal	1 8	66.15	33.85	1.00	distinct, with clod, sale.
	Parkgate, main coal	7 0	67.14	30.73	2.13	four feet, blast furnaces.
	Old Parkgate vein	4 6	65.09	33.28	1.63	hard, in laminæ ,,

FAT, BITUMINOUS COALS OF YORKSHIRE AND SCOTLAND.

Description and Locality of Coal Veins.	By whom analysed and described.	Thickness of each seam.	Analysis of 100 parts of coal.		
			Carbon.	Bitumen, volatile matter, water, &c.	Ashes or cinders.
		ft. in.			
YORKSHIRE.					
Parkgate, top coal, upper part of the 7 ft. cl.	D. Mushet	1 4	62.51	36.49	1.00
,, bottom part	,,	1 8	66.94	31.56	1.50
Birkenshaw coal	,,	..	64.96	32.54	2.50
Worsboro' furnace coal	,,	9 0	60.32	38.18	1.50
,, another specimen	,,		56.45	40.85	2.50
Milton, main coal, splint part	,,	9 0	69.40	27.60	3.00
,, roof or soft part	,,		62.71	36.04	1.25
Thorncliffe, thin furnace coal	,,	2 6	63.98	35.52	.50
Smithy wood coal	,,	2 6	54.60	44.27	1.13
Easley Park	,,	1 7	69.12	30.00	.88
Yorkshire Kent coal	,,	5 0	66.40	32.72	.88
Stafford, main coal, 5 feet bottom part	,,	3 0	62.08	35.67	2.25
,, ,, top part	,,	2 0	68.12	30.20	1.68
Silkstone, main coal	,,	..	65.08	32.29	2.63
,, soft or clod coal	,,	5 0	63.10	35.15	1.75
SCOTLAND.					
Clyde, upper vein, top	,,	..	37.00	41.50	21.50
,, ,, bottom	,,	..	53.45	44.80	1.75
,, second vein	,,	..	42.10	48.34	9.56
,, third or furnace	,,	..	51.20	45.50	3.30
,, fifth splint coal	,,	..	53.40	42.40	4.20
Calder, furnace coal, top	,,	..	49.98	43.82	6.20
,, ,, splint part	,,	..	50.67	47.48	1.85
,, ,, main coal, top	,,	..	49.60	49.39	1.01
,, ,, middle	,,	..	52.30	39.95	7.75
,, ,, bottom	,,	..	51.60	44.51	3.89
Gleh Buck, furnace coal	,,	..	53.20	45.20	1.60
,, inferior coal	,,	..	48.80	44.20	7.00
Cleugh, furnace coal	,,	..	47.08	42.25	10.67
Omoa, splint ,,	,,	..	..	46.62	—
,, bright ,,	,,	..	..	47.29	—
Marystone Pyat, shaw coal, top	,,	..	49.60	49.31	1.09
,, pine splint	,,	..	51.82	46.57	1.61
,, heavy splint	,,	..	54.67	39.25	6.08
Fat, bituminous Coals.					
Govan coal, first vein, top part	,,	..	49.55	44.65	5.80
,, ,, lower part	,,	..	49.41	48.92	1.67
,, second vein	,,	..	42.20	48.34	9.46
,, fifth vein, splint	,,	..	48.84	49.79	1.37
,, sixth vein, lower main					
1. Craw coal	,,	..	51.58	44.60	3.82
2. Head coal	,,	..	48.08	49.38	2.54
3. Ground coal	,,	..	44.57	51.00	3.43
4. Foot coal	,,	..	52.27	44.15	3.58
Lismahago, cannel coal	,,	..	39.43	56.57	4.00
Dry Coals, not very adhesive.					
Clyde, splint coal	,,	..	59.00	36.80	4.20
,, ,,	Thomson	..	55.23	35.27	9.50
,, clod coal	D. Mushet	..	70.00	26.50	4.50
,, soft coal	Thomson	..	42.25	47.75	10.00
,, near Glasgow	Dufrenoy and Berthier	..	64.40	31.00	4.60
Calder ,,	,,	..	51.00	45 00	4.00
Monkland ,,	,,	..	56.20	42.40	1.40
Middlerig	Dr. Fyfe	..	50.50	42.00	7.50
Scotch coal	W. R. Johnson	..	48.81	41.85	9.34
,, cannel	,,	..	60.34	36.95	2.71
,, ,,	Dr. Ure	..	39.40	56.60	4.00

ANTHRACITES OF EUROPE.

Localities.	By whom examined and analysed.	Specific gravity.	Analysis 100 parts. Carbon.	Hydrogen, water, and volatile matter.	Silica and ashes.
South Wales.					
Anthracites.					
Welsh anthracite, Cwm Neath	Dr. Schafhaeutl	..	92.42	5.97	1.91
		..	94.10	4.90	.93
Ynis Cedwin, Crane	Jno. F. Frazer	..	86.60	7.60	5.80
,,	W. R. Johnson	1.336	87.60	9.18	4.32
		1.372			
Welsh stone coal	D. Mushet	1.368	89.70	8.00	2.30
Welsh slaty stone coal	,,	1.409	84.17	9.10	6.73
Mean of several varieties of Welsh coal	Dr. Ffye's Experiment	1.354	71.40	17.80	10.80
European Continent.					
Anthracitous Coals.					
The Alps, Isere, Canton of Launure	M. Robin	..	..	..	.40
Canton of Lanton, near Grenoble	,,	1.072	..	..	..
Westphalia	M. Karsten	1.358	..	..	..
,,	,,	1.336	..	..	..
Mean analysis of twelve varieties of anthracite	Berthier	..	79.15	7.37	13.25
Dry or slightly Bituminous Coals.					
Ireland.					
Kilkenny, Leinster	D. Mushet	1.602	92.88	4.25	2.87
,, slaty or cannel	,,	1.445	80.47	13.00	6.53
Boolavoonein, stone coal	,,	1.436	82.96	13.80	3.24
Corgee ,,	,,	1.403	87.49	9.10	3.40
Queen's county, Leinster	,,	1.403	86.56	10.30	3.14
Kilkenny, cannel	Karsten	..	74.47	25.01	.50
Kilkenny	Dr. C. T. Jackson	..	79.60	12.00	8.40
Scotland.					
Coal, under Basalt, Renfrewshire	D. Mushet	..	69.74	16.66	13.60
France.					
Mean of twelve specimens	M. Berthier	..	79.15	7.37	13.25
Côte d'or, Sincey	De Nerville	..	82.60	8.60	8.80
Mais Salze	M. Varin	..	83.00	7.50	9.50

BITUMINOUS COALS OF FRANCE.

Departments, Coal Basins, and varieties of Coal.	Locality.	Concessions.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
*Basin of Fins	Montet	.. ..	M. Baudin ..	1.38	75.23	24.77	—
	Gabeliers	.. ..	„	1.34	74.92	25.08	—
	Deux Chaises, Chapelle	.. ..	„	1.48	74.22	25.78	—
	Fins	.. ..	„	..	68.28	31.72	—
	Noyant	.. ..	„	1.30	62.49	37.51	—
*Basin of Bussiere-la-grue	..	.. ..	„	1.34	54.76	45.24	—
*Basin of Bert	..	.. ..	„	1.36	58.47	41.53	—
					64.20	35.80	—
*Basin of Commentry	Commentry	.. ..	M. Regnault	..	63.20	36.60	1.20
	Chambled	Marais	„	1.38	87.85	12.15	—
	Commentry	Amenat	„	1.27	60.00	40.00	—
	Néris	Great bed	„	1.35	58.87	41.13	—
	Id.	Ferrières	„	1.31	56.76	43.24	—
*Basin of Doyet	Doyet	La Souche	„	1.30	61.23	38.77	—
	Monticq	Bourdignat	„	1.28	59.58	40.42	—
	Id.	Chauvais	„	1.30	58.61	41.39	—
	Bezenet	Grande masse	„	1.32	56.84	43.16	—
Champagnac in the coal basin of Haute-Dordogne —Cantal	Mines de Lempret	New bed 1	M. Baudin ..	1.26	66.60	30.19	4.60
		2 metres 2	„	1.33	56.30	29.80	13.90
		 3	„	1.36	53.20	30.30	16.50
		Upper bed 4	„	1.28	65.70	30.10	4.20
		 5	„	1.27	62.40	30.60	7.00
	Mine de Madie	First or lowest bed 6	„	1.28	60.70	32.90	6.40
		2d bed 7	„	1.28	64.00	31.60	4.40
	Maurinc	Madie	M. Berthier	..	61.00	34.50	7.50
Coal basin of Haute-Dordogne —Cantal	1. Messeix	Clydance	„	1.39	85.49	14.51	—
	2. Singies	Morilleux	„	1.38	71.27	28.73	—
	3. Lempret	New bed	„	1.38	69.10	30.90	—
	4. Madie	2d bed	„	1.27	68.97	31.03	—
	5. Prodelles	3d bed	„	1.40	67.28	32.72	—
	6. Vendes	Champlaix	„	1.38	66.08	33.92	—
	7. Madie	1st bed	„	1.31	66.05	33.95	—
	8. Singles	Ginguette	„	1.32	65.14	34.86	—
	9. Lempret	C. de l'air	„	1.35	63.08	36.92	—
	Mandailles	Lignite	„	1.29	41.45	58.55	—
	Chambeuil	Lignite	„	1.28	40.88	59.12	—
†Auvergne, Central France, department of Puy-de-Dôme.	1. Charbonnier	Great bed	M. Baudin ..	1.43	86.41	13.59	—
	2. La Combelle	.. ..	„	1.38	80.31	19.69	—
	3. „	La Ronziere	„	1.36	78.82	21.18	—
	4. Armots	Fontaine-du-Chien	„	1.38	77.48	22.52	—
	5. ..	Chamas	„	1.41	76.79	23.21	—
	6. Gras Ménil	Great bed	„	1.35	75.31	24.69	—
	7. Fondary	Les Vignes	„	1.30	75.15	24.85	—
	8. La Taupe	Arrest	„	1.32	73.89	26.11	—
	9. Mégécoste	6th bed of 4 ft.	„	1.34	73.01	26.99	—
	10. La Taupe	Great mass	„	1.32	71.80	28.20	—
	11. Les Barthes	Bastard of 3 ft.	„	1.36	74.40	28.60	—
	12. ..	8 feet bed	„	1.39	70.14	29.86	—
	13. Mégécoste	7th bed of 8 ft.	„	1.34	70.09	29.91	—
	14. Les Barthes	3 feet	„	1.45	70.07	29.93	—
	15. Mégécoste	6 feet bed	„	1.34	69.86	30.14	—
	16. Les Barthes	3 feet	„	1.35	68.64	31.34	—
	17. Mégécoste	7 feet	„	1.49	67.08	32.92	—
	18. Les Barthes	Le Feu	„	1.33	66.78	32.22	—
	19. Brioude	Preissat	„	1.32	59.43	40.57	—
Basin of Brassac, mines of La Taupe and Arrest	Near Guinguette	Cingles	„	..	63.90	32.00	4.10
	..	Agassiz bed	„	1.340	65.00	26.40	8.60
	..	La Louise bed	„	1.310	68.50	26.80	4.70
	..	Four feet bed	„	1.320	66.20	27.00	6.80
	..	La Felicité bed	„	1.300	67.50	26.00	6.50
	..	La Trouelle	„	1.330	66.10	26.30	6.60
Basin of St. Kloy, or Montaigne	La Roche	.. ..	„	1.300	59.80	40.20	5.20
	La Vernarde	.. ..	„	1.300	60.40	39.60	8.70
Basin of Bourg Lastic	Messeix	.. ..	„	1.390	86.24	13.76	5.20
	Singles	.. ..	„	1.380	75.00	25.00	13.00
	„	.. ..	„	1.320	68.00	32.00	8.20

* Coal of the Bourbonnais, department of Allier.

† Coal Basin of Brassac.

BITUMINOUS COALS OF FRANCE, DEPARTMENT OF PUY-DE-DOME.

Departments, Coal Basins, and varieties of Coal.	Locality.	Concessions.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
	Puy S. Gulmier..	De Chiex	M. Baudin ..	1.340	84.45	15.55	—
	La Besette	Vazazène	,,	1.280	66.75	33.25	—
Saone and Loire.	St. Bérain	Molliere	M. Gruner ..	..	74.00	..	28.52
		Jumeaux	,,	..	68.75	..	22.63
		,, 1st class	,,	..	68.75	..	24.00
		Vignes	,,	..	73.52	..	26.50
		Quatre Bras ..	,,	..	66.80	..	19.80
		St. Charles	,,	..	69.25	..	22.10
Basin of Creusot and Blauzy	Maillot.....	.. ..	,,	..	59.50	..	12.20
	Communautés ..	.. ..	,,	..	67.75	..	5.45
	Montchanin	.. ..	,,	..	61.25	..	9.00
	Longue Pendue..	.. ..	,,	..	60.00	..	8.00
	Ragny	.. ..	,,	..	63.20	..	8.55
	Blanzy	Montceaux	,,	..	58.00	..	5.00
	Lucy.....	Lucy.....	,,	...	65.00	..	14.00
Saone et Loire.....	Basin of Epinac..	.. ..	Regnault....	..	61.10	36.40	2.50
Provence. Basse Alpes	Volx	Lignites	M. Diday....	..	51.70	42.50	5.80
	Dauphin				49.20	46.30	4.50
	Volx				39.20	45.80	15.00
	Dauphin				34.70	53.10	12.20
	Sigonce.....				40.60	52.40	7.00
	Manosque				31.20	50.50	18.30
	Villemus				38.90	51.50	9.60
	Pierre-vert				28.00	45.80	26.20
Var.	Cadiere.....				48.10	44.80	7.10
	St. Zacharie				32.40	61.60	6.00
	Beausset				40.60	39.40	20.00
Vaucluse	Méthamis				40.90	50.00	9.10
	Piolenc.....				26.60	51.10	22.30
	,, ...				41.50	52.30	6.20
	Moutragon.....				36.80	48.20	15.00
*Basin of Saint Etienne	Du Soleil.....	Monteel	M. Gruner ..	..	74.59	19.60	2.81
	St. Marie.....	Chaney..... 1	,,	..	74.81	21.67	3.52
	St. Claude	Méons 1	,,	..	74.31	24.17	1.52
	,, ...	,, ... 2	,,	..	73.80	23.13	3 07
	St. Marie.....	Chaney..... 2	,,	..	73.78	24.33	1.89
	Reveux.....	Reveux.....	,,	..	72.73	22.83	4.44
	St. Claude	Méons 3	,,	..	72.13	24.47	3.40
	Caraude	Cote-Thiolière.	,,	..	69.13	25.67	5.20
	..	Grande couche du cros.....	,,	..	69.27	24.50	6.23
2d class. Ordinary Coals of Saint-Etienne	Chené	5. De la Roche.	,,	..	67.96	28.47	3.57
	Vincent	5. Bérnard.....	,,	..	66.66	29.20	4.14
	Deville.....	3. De la Roche.	,,	..	65.72	31.90	2.38
	,, ...	3. ,,	,,	..	61.05	32.54	6.41
	,, ...	7. ,,	,,	..	66.35	28.27	5.38
	St. André.....	Méons	,,	..	65.68	27.83	6.49
	Pompe	7. Du. Treuil ..	,,	..	62.89	29.73	7.38
	,, ...	7. ,,	,,	..	58.81	26.03	15.16
	Vincent	7. Bérard.....	,,	..	63.71	25.27	11.02
	,, ...	6. ,, ...	,,	..	63.94	27.13	8.93
3d class. Fat Coals, longue flamme	Montrambert..	Great bed, 1st quality	,,	..	57.82	34.10	0.08
		2d ,,	,,	..	54.56	35.43	10.01
	Littes	Beraudière	,,	..	58.79	35.57	5.64
	Great bed.....	1st quality	,,	..	59.29	35.20	5.51
†Bouches du Rhone	Lignites of Greasque....	Mène du haut 1	M. Diday....	..	48.20	49.00	2.80
		Bleu 2	,,	..	48.50	48.00	3.50
		Menette 3	,,	..	45.60	46.60	4.80
		Maitre Jean.. 4	,,	..	41.90	51.60	6.50
		La Fortune.. 5	,,	..	44.70	52.30	3.00
		La Saoude .. 6	,,	..	43.70	47.80	8.50
		La Ravette .. 7	,,	..	39.10	53.90	7.00
‡Ardennes.....	Séchwal	Peat	M. Sauvage..	..	22.00	69.70	8.30
‡Basses-Alpes	Lauzanier	,, ...	M. Diday....	..	9.00	58.00	33.00
†Basses-Pyrénées..	Bayonne	Lignite.....	M. Gruner ..	..	48.50	38.10	13.70
†Lozère and Aveyron	Rosiers.....	,, ...	..	..	50.70	47.60	1.70
	Peyre lau.....	,, ...	M. Cochon ..	..	49.10	46.20	4.70
†Gard.....	Alais.....	St. Christol, lig.	M. Varin	..	34.00	46.00	20.00
†Bouches-du-Rhone	Rocher Bleu ..	Great lig'te bed	M. Diday....	..	50 20	46.30	3.50
	Belcodène	Smaller beds of lignite ..	,,	..	45.20	52.40	2.40
					26.50	53.50	20.00

* Fat Coals, very rich in carbon, first class. † Lignite Beds. ‡ Peat.

BITUMINOUS COALS OF FRANCE, DEPARTMENT OF PUY-DE-DOME.

Departments, Coal Basins, and varieties of Coal.	Locality.	Concessions.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
Var.	Collobrieres	Coal	M. Diday	..	63.00	28.00	9.00
		1. Fournier	M. Varin	..	76.00	16.00	8.00
		2. Plomb	„	..	70.00	17.00	13.00
	La Grande Combe	3. L. Barraque.	..	..	80.50	14.50	5.00
		4. Abilon	„	..	81.00	14.00	5.00
		5. Velours	..	..	75.00	14.00	11.00
		6. Bosquet	„	..	74.00	20.00	6.00
		7. Rotschild	..	..	73.50	16.50	10.00
		8. Levape	..	..	77.00	18.00	5.00
*Coals in Arrondissement of Alais, Department of Gard	Prescol	9. Trois-Machoires	„	..	77.50	18.00	4.50
		10. Cing-pans	„	..	78.00	19.50	2.50
	Partes	11. Taranière	..	..	65.00	18.50	16.50
		12. Rowière	„	..	78.50	14.00	7.50
	Bessége	13. Great bed	„	..	67.50	20.50	12.00
	Champelauzon	14. Champelauzon	..	..	79.50	13.00	7.50
	St. Jean-de-Valeriste	15. Remise	„	..	72.00	9.00	19.00
	St. Paulet	16. Lignite	„	..	36.50	51.00	12.50
	Connaut	17. „	„	..	35.00	51.00	14.00
Coal basin of Alais, department of Gard	1. Bessége	Coal	„	..	68.50	25.50	6.00
	2. Saint Cristol	Lignite	„	..	34.00	46.00	20.00
	3. Grand Combe	Coal	„	..	80.50	17.00	2.50
	4. „	Pin bed	„	..	74.00	18.50	7.50
	5. Bessége	Coal	„	..	63.00	24.50	12.50
	6. Grand Combe	Plomb	„	..	77.50	19.00	3.50
	7. Cessous	Mean of 3 expe.	„	..	78.30	17.70	4.00
	8. „	Masse bed, 3 ex.	„	..	58.50	26.50	15.00
	9. „	Salze bed, 2 exp.	„	..	83.00	7.50	9.50
	Rochebelle	.. ..	M. Bertheir	..	68.00	21.60	11.40
Hérault	Saint-Gervais basin	Concessions 2 of Bous- 3 quetd'orbe 4 and Grais- 5 sesac 6	M. Garella	..	56.50	17.00	26.50
			„	..	77.50	19.00	3.50
			„	..	70.50	16.00	13.50
			„	..	69.70	15.00	15.40
			„	..	65.20	18.50	16.30
			„	..	68.80	31.20	15.30
		Graissesac		..	85.16	14.84	14.05
		St. Gervais	M. Gruner	..	78.30	16.40	5.30
Aveyron	Basin of Aubin, or Decazeville	Paleyret, No. 3	M. Senez	..	67.50	26.60	5.90
		„ 4	„	..	61.00	32.80	6.20
		Bourran	„	..	71.50	24.60	3.90
		Fontanges	„	..	63.00	27.20	4.20
		Fareiret	„	..	53.00	38.30	8.70
		Bouquiès	„	..	69.80	25.10	5.10
		Cransac	„	..	53.20	39.30	7.50
		Lavergne	„	..	50.00	42.00	8.00
		Le Poux	„	..	55.00	38.00	7.00
		Lagrange	M. Regnault	..	61.20	34.20	4.60
Tarn	Basin of Carmeaux	Grand-Vein	..	..	72.60	23.60	3.80
		Castillan	..	..	74.50	20.90	4.60
Aude	Basin of Ségure	.. ..	M. Berthier	..	56.00	24.00	20.00
			M. Bois	..	60.00	22.00	18.00
			M. Leplay	..	71.60	24.00	4.40
	Basin of Durban	.. ..	M. Berthier	..	49.00	33.50	17.50
		Anzin, bitumens	Chevalier	1.284	74.25	25.00	0.75
Nord	Basin of Valenciennes	Fresnes anthrc'e	„	1.360	89.30	7.20	3.50
		Anzin	Berthier	1.284	71.50	25.00	3.50
Haute-Saône	Gémonval	Corcelles & Lure	M. Drouot	1.440	48.90	36.60	14.50
Vosges	Norroy	.. ..	M. Regnault	1.410	—	—	—
Rhone	Rive-de-Gier	Grand-Croix	..	1.298	67.20	31.00	1.80
			..	1.302	68.80	29.80	1.40
		Cimitière	..	1.288	68.40	28.00	3.60
			..	1.294	67.00	30.00	3.00
		Couzon	..	1.298	62.80	34.50	2.70
			..	1.311	62.10	32.60	5.30
		Corbeyre	..	1.315	74.00	23.00	7.00
		Couzon	M. Gruner	..	63.55	30.93	5.52
		Grézieux	„	..	62.54	25.10	12.36
		Couzon	„	..	62.57	30.07	7.34
Doubs	..	Morteau	M. Boyé	..	29.50	53.50	17.00
		Flangebouche	„	..	30.00	62.00	8.00
Jura	..	Orbagna	„	..	30.50	57.50	12.00

* Bituminous Coals in France.

ANALYSIS OF COMBUSTIBLES, EUROPE.

Departments, and varieties of Coal.	Locality.	Designation of Coal Beds.	By whom analysed.	Analysis.		
				Carbon.	Volatile matter.	Ashes.
Deux Sévres.....	Chantonnay	Main coal	M. Boyé	62.70	20.00	17.30
Vendee	Basin of Vouvant	Faymoreau	M. Berthier..	61.15	29.50	6.15
				65.10	27.50	7.40
Loire Inférieure.....	Ancenis	Guignardiere	M. Sentis.....	58.50	31.00	10.50
Finistêrre	Plogoff.....	Cap. Sziain	,, ...	63.00	25.00	12.00
FRANCE.	Layon et Loire	Pits of St. Barbe	M. Sentis	80.21	17 00	3.79
				77.59	18.00	4.41
		Du Bocage	and	82.39	13.20	4.41
		Des Barres	M. Lechatelier.	67.03	16.60	16.37
		The West	,,	69.92	18.00	12.08
	Mont-jean	St. Nicholas	,,	65.88	23.40	10.72
				73.76	22.34	3.90
		Beau-soleil.....	,,	74.02	19 20	6.78
Coals of Maine et Loire.	St. Georges.... Sur Loire.....	The Arch.....	,,	63.40	27.87	8.73
	Chaudefonds ..	St. Barbe.....	,,	73.57	10.00	16.43
		St. Nicolas	,,	71.78	11.60	16.62
	St. Georges....	Conception.....	,,	72.71	15.60	11.69
				65.00	23.80	11.20
	Chatelaison....	Adele.....	,,	80.99	9.40	9.61
		Du Pavé	,,	78.10	18.40	3.50
	Doué.....	De Minières	,,	65.28	27.80	6.92
Haute-Loire.....	Basin of Langeac		M. Baudin	74.00	26.00	7.10
Feroe Islands	Suderoë I.	Brown coal.....	Durocher.....	24.50	37.50	38.00
Hesse Cassel ..... (Coals)	Meissmer	Anthracite	M. Kuhnert ..	70.19	14.34	15.47
	,, ...	Pechkohle	,,	56.60	40.97	2.43
	Hirschberg.....	,, ...	,,	60.83	38.36	0.81
	Habichtwald	,, ...	,,	57.26	35.41	7.33
	Hirschberg.....	Dry coal	,,	66.11	31.13	2.76
Hesse Cassel ..... (Lignite)	Habichtwald ..	Lignite, passing to coal	,,	54.18	42.49	3.33
	,, ...	Inferior lignite ..	,,	52.98	42.10	4.92
	,, ...	Middle ,, ..	,,	54.96	41.84	3.20
	Rigenkuhl	Woody ,, ..	,,	51.70	47.01	1.29
	Stillberg	Lignite.....	,,	50.78	42.27	6.95
		Peat or turf ..	D. Mushet	25.20	72.60	2.20
			Marcher	65.00	22.00	13.00
			,, ...	37.00	48.00	15.00
Southern Russia....	Cossack	Countryof theDon best anthracite.	Voskressensky	94.23	—	—
	Don					
	Tiflis.....	Inferior	..	63.64	—	—
ITALY.						
Principality of Monaco	Menton	Earthy	M. Diday.....	49.20	29.90	20.90
SPAIN.	Cueva	One yard coal....	I. T. Cooper ..	66.00	31.80	2.20
	Emanuela	Three yard coal..	,,	67.90	30.90	2.10
	Viena Alta	Four yard coal ..	,,	63.60	33.90	2.50
Coals of Asturias ..	.. ..	Mine of Clausel.	M. Berthier ..	35.00	53.00	12.00
	.. ..	Del Regueron....	,,	43.00	44.00	13.00
	.. ..	Mean of 5 other mines	,,	53.00	40.00	7.00
	Tudela	.. ..	M. Paillette....	65.80	32.27	1.93
	Mieres	.. ..	,,	57.60	39.40	3.00
	Lama	.. ..	,,	66.69	41.51	1.80
	Oloniego	.. ..	,,	60.40	36.55	3.05
	Arnao	.. ..	,,	45.69	45.11	9.20
	Ferrones	.. ..	,,	46.98	46.91	6.11

BITUMINOUS COALS IN BELGIUM.

Countries, Provinces, and varieties of Coal.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Oxygen & hydrogen.	Ashes.
Province of Hainault.	Dour	.. ..	Berthier	..	71.50	23.30	5.50
	"	.. ..	"	1.307	88.00	..	2.50
	"	.. ..	"	..	85.00	12.70	2.30
	.. ..	.. ..	M. Canchy	1.276	84.67	13.23	2.10
	.. ..	.. ..	"	1.292	83.87	12.47	3.68
Near Mons	Basin of Mons	Plate seam	M. Chevalier	1.273	..	..	1.98
	"	.. ..	"	1.263	..	..	1.27
	"	.. ..	Karsten	1.307	85.50	12.00	2.50
	Canton of Dour	.. ..	Berthier	1.270	71.50	23.30	5.20
	Near Mons	Bouleau	"	1.270	65.30	33.00	1.70
	.. ..	Grand Gaillet	"	..	58.50	38.50	3.00
	.. ..	Gade vein	"	..	51.00	44.00	5.00
Province of Liege.	Liege	St. Margarite	C. Davreax	..	78.30	17.80	3.90
	"	Olisson	"	..	76.00	19.60	4.40
	"	Cerisier	"	..	69.90	23.40	6.70
Dry coals	Harion	L'Harbe S. Michael	"	..	72.60	24.20	3.20
			"	..	68.50	21.20	10.30
			M. Delvaux	1.365	81.90	9.00	9.10
Ditto	Chokier	Petite Hareng	"	1.286	71.68	16.36	11.96
Ditto	Bonnier	Moset seam	"	1.318	91.38	8.00	6.12
GERMANY. Bituminous Coals.							
Upper and Lower Silesia	Waldenberg	Glanz coal	Richter	..	57.20	36.40	6.40
	Snbrze	"	"	..	63.20	32.93	3.90
	Bielschowitz	"	"	..	58.17	37.89	3.93
	Leopoldinengrube	"	Gay Lussac	..	61.50	35.62	2.88
	Frederich zu Zawada	.. ..	Karsten	1.263	57.90	42.00	2.10
	Gustaw Grube	.. ..	"	1.270	68.00	30.10	1.90
Saxon States	Sälzer	Newark	"	1.288	81.60	17.70	0.70
	"	"	Gay Lussac	..	80.10	18.90	1.00
Prussian Saxony	Circle of the Saale	Wettin or Wittenberg	Karsten	1.466	56.70	18.90	24.40
Germany	Brown coal	Shraplau	..	..	20.25	62.25	17.50
	Eschweiler	Flotz Gyr	Gay Lussac	..	82.40	16.42	1.18
	.. ..	"	Karsten	1.300	80.23	18.60	1.17
Saxony	Pottschapel	Gate Schicht	"	1.454	41.00	31.30	27.70
	Planitz	Pitch coal	"	1.860	63.40	35.20	1.40
Bohemia	Elbogen	Brown coal	M. Balling	..	37.18	56.16	6.66
	Schlakenwerth	Carbonized peat	M. Debette	..	67.00	30.00	3.00
Wurtemburg	Kœnigsbrunn	Raw peat	M. Berthier	..	24.40	70.60	5.00

BITUMINOUS COALS IN ASIA.

Country.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
HINDOSTAN.							
Pres. Bengal	Nerbudda	Fatephur	..	..	22.00	14.00	64.00
	Chirra Ponoje	Slaty	..	1.447	41.00	36.00	23.00
Assam	Cossyah or Kosya hills	Few ashes	..	1 275	60.70	38.50	.80
Pres. Bengal	Prov. Delhi	Hurdwar	..	1.368	50.00	35.40	14.60
Birmese coast	Aracan	.. ..	..	1.388	33.00	66.40	0.60
Turkey in Asia	Anatolia	Heraclea	Prof. Hitchcock	..	62.40	31.80	5.80
Syria	Mount Lebanon	Asphaltum	"	..	24.40	68.00	7.60
	Mount Hermon	Anti-Libanus	"	..	14.00	72.60	13.40

SEMI-BITUMINOUS OR DRY COAL—AMERICA.

State and County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific gravity.	Analysis. Carbon.	Volatile matter.	Ashes.
Tennessee..	Cumberland mountains .	Kimbrow's vein..	Dr. Troost	1.450	71.00	17.00	12.00
	,,	Gillenwaters	,,	1.450	69.00	14.00	17.00
Kentucky ..	Hawsville ...	Splint or cannel coal	Dr. Jackson ..	1.250	48.40	48.80	2.80
	Caseyville	Bituminous coal .	Johnson	1.392	44.49	31.82	23.69

FAT BITUMINOUS COALS IN WESTERN VIRGINIA.—STATE REPORTS.

County.	Locality.	Designation of Coal Beds.	Analysis. Carbon.	Volatile matter.	Ashes.
[Upper coal series.]	Clarksburg.	Main seams	56.74	41.66	1.60
	,, ...	,, ...	49.21	45.43	5.36
	Pruntytown	,, ...	57.60	39.00	3.40
	Morgantown	,, ...	60.54	37.30	2.14
Lower coals—Valley of the Ohio. Kanawha	1. Coal creek	Judge Summers's bank.....	55.55	41.85	2.60
,, ...	2. Grand creek	,, ...	52.75	43.20	4.05
Logan	3. Wolf creek, Big Sandy river....	Burning spring.....	47.15	48.00	4.85
Kanawha	4. Big Coal river	(Lewis')	50.20	47.10	2.70
,, ...	5. Three mile creek ..	Cartrell's.....	45.95	50.30	3.75
,, ...	6. Elk river.....	Friend's mines.....	55.90	39.90	5.20
Logan	7. Logan Court-house	Lawson's.....	58.35	39.50	2.15
,, ...	8. Guyandotte	Trna fork.....	56.50	42 00	1.50
,, ...	9. Big Sandy river ..	Pigeon creek.....	55.00	41.00	4.00

MODERATELY BITUMINOUS COALS IN WESTERN VIRGINIA.

County.	Locality.	Designation of Coal Beds.	By whom analysed.	Analysis. Carbon.	Volatile matter.	Ashes.
Formation No. XI. Rogers.		Little Sewell Mountain..	Wm. B. Rogers	80.24	17.48	2.28
		,,	,,	77.64	17.36	5.00
	Big Sewell Mn.	Rogers's seam ..	,,	75.88	22.32	1.80
	E. side, W. flank	Tyree's bed.....	,,	67.84	30.08	2.08
	,,	Deem's bed.....	,,	71.73	27.13	1.14
Fayette	Mill creek	Paris's bank	,,	71.68	26.20	1.92
	Scrabble creek ..	.. ..	,,	63.36	29 04	7.60
	Bell creek	.. ..	,,	..	32.16	..
	Keller's creek....	Hansford's	W. B. Rogers's State Report	60.92	37.08	2.00
Lower Coal series in the Valley of the Kanawha.	Second seam	Storkton's mine .	,,	74.55	21.13	4.32
	Campbell's creek	Ruffner's 2d seam	,,	55.76	32.44	11.80
	,,	Noyes's seam....	,,	64.16	32.24	3.60
	,,	,,	,,	65.64	31.28	3.08
	Cox's creek.....	3d seam	,,	51.41	42.55	6.04
	Faure's bank	Upper seam	,,	53.20	35 04	11.76
	L. Ruffner's bank	,, ...	,,	49.84	44.28	5.88
	Bream's bank....	3d seam	,,	57.76	33.68	8.56
	Smither's bank ..	.. ..	,,	54.52	29.76	15.76
	Hughes's bank ..	.. ..	,,	62.32	32.88	4 80
	D. Ruffner's bank	Upper seam	,,	57.28	35.08	7.64
	Warth's bank....	.. ..	,,	54.00	39.76	6.24

Bituminous Coals in EASTERN VIRGINIA, in the Chesterfield, Powhaton, Goochland and Henrico Basins.

Preston & Mongalia Counties —Basins containing the Lower Coal Series.

Hampshire & Hardy Counties —Basins containing the Lower Coal Series.

County.	Locality.	Designation of Coal Beds.	By whom analysed.	Analysis.		
				Carbon.	Volatile matter.	Ashes.
Semi-Bituminous, or Dry.						
Montgomery	Thom's creek	Strouble's run	Wm. B. Rogers	80.20	13.60	6.20
	Lewisburg	" "	"	78.84	14.16	7.00
Botetourt	Catawba	" "	"	78.50	16.50	5.00
Hampshire	Brantzburg, N. br. Potomac	2 m. above m. of Savage	" "	72.40	19.72	7.88
	Olwer's tract	12 feet seam	" "	79.08	16.28	4.64
"	Nr. Westernport	Sigler's mine	" "	82.60	15.76	2.64
Maryland	Lonaconing	12 feet seam	" "	77.43	19.37	3.20
"	Abraham's cr.	Macdonald's 3d seam	" "	74.00	18.60	7.40
	1 mile from top of Alleghany	Near Turnpike	" "	77.12	19.60	3.28
	Vandover's	N. W. Turnpike	" "	61.44	14.28	24.28
Hardy	Kitzmiller's	" "	" "	79.76	15.48	4.76
"	Falls of Stony riv.	Lower seam	" "	79.16	15.52	5.32
	Abraham's creek	Michael's	" "	72.40	15.20	12.40
	Stony river	N. of Turnpike	" "	83.36	13.28	3.36
	Michael's	Upper part	" "	45.24	14.96	39.80
Preston	Kingswood	Fairfax's	State reports	53.77	31.75	14.48
"	"	Middle seam	" "	65.32	27.77	6.91
"	"	Forman's basin	" "	73.68	21.00	5.32
"	Deck Hollow, c.	Martin's	" "	65.42	23.42	11.16
"	Buffalo Lech run	Beatty's	" "	62.56	29.60	7.84
"	Big Sandy	N. Brandon's	" "	67.60	22.40	10.00
"	N. Brandonville	Morton's	" "	65.28	30.80	3.92
"	Cheat river, n. Kingswood	Price's	" "	60.36	25.00	14.64
"	Big Sandy, W. side	Seaport's	" "	66.64	27.12	6.24
"	Kingswood	Hagan's	" "	68.32	26.48	5.20
"	"	"	" "	67.28	29.68	3.04
"	Big Sandy basin	W. side Cheat	" "	60.04	26.88	13.08
"	Kingswood	Cresaps	" "	64.24	30.24	5.32
South sd. James riv. 1	Stonehenge	Chesterfield	" "	58.70	36.50	4.80
Chesterfield 2	Maidenhead	Engine shaft	" "	63.97	32.83	3.20
" 3	Heth's pit	"	" "	62.35	37.65	2.80
" 4	Mill's and Reid's	Creek pit	" "	57.80	38.60	3.60
" 5	Wills's pit	"	" "	62.90	32.50	4.60
" 6	"	Green hole shaft	" "	67.83	30.17	2.00
" 7	Heth's deep shaft	Bottom seam	" "	53.36	35.82	10.82
"	"	Middle seam	" "	66.50	28.40	5.10
"	"	Top seam	" "	61.68	28.80	9.52
" 8	Powhatan pits	Finney	" "	59.57	32.33	7.80
" 9	Winterpock creek	Cox's mine	" "	65.52	29.12	5.36
	Cloverhill, Appomattox river	Slate coal	G. W. Andrews	55.00	38.50	6.50
	"	Mean of 4 spec	Johnson	54.83	33.04	10.13
	Richmond coal	" "	Andrews	59.25	32.00	8.75
	Mid Lothian	Wooldridge's p	Johnson	61.08	28.45	10.47
	"	Mean result, av. size coal	"	53.01	33.25	14.74
	Creek Coal Co.	Mean of 6 trials	"	60.30	31.13	8.57
	Black Heath pits	Mean of 4 spec	"	58.79	32.57	8.64
	Tippecanoe pits	"	"	54.62	36.01	9.37
North side of James river 10	" "	Randolph's	W. B. Rogers State report	66.15	30.50	3.35
11	Coalbrook dale	Second seam	"	66.48	29.00	4.52
12	Anderson's pit	First seam	"	66.78	28.30	4.92
13	Barr's pits	"	"	70.80	24.00	5.20
14	"	Second seam	"	54.97	22.83	22.20
15	"	Third seam	"	65.50	24.70	9.80
16	"	Fourth seam	"	56.07	21.33	22.60
17	Crough's Lower shaft	Upper seam, 110 ft. from surface	"	64.60	30.00	5.40
	"	Mean of 4 spec	Johnson, State report	67.32	23.96	8.72
18	Scott's pitt	" "	"	60.86	33.70	5.44
19	Waterloo shaft	" "	"	55.20	26.80	18.00
20	Deep Run pits	" "	"	69.84	25.16	5.00
	"	Mean of 40 sp.	"	67.96	21.57	10.47
	Wills's pit	Upper vein	T. G. Clemson	66.60	28.80	4.60
	Anderson's pit	Bottom seam	R. C. Taylor	64.20	26.00	9.80
	Chesterfield	Called natural coke	W. B. Rogers State report	80.30	9.98	9.72
	"	"	"	70.00	16.00	14.00
	"	"	Prof. Bailey	68.00	17.00	15.00
	"	Mineral charcoal	T. G. Clemson	83.30	10.70	6.00

SEMI-BITUMINOUS OR DRY COALS IN THE STATE OF MARYLAND.—THE CUMBERLAND OR FROSTBURG COAL REGION, OCCUPYING A SMALL PART OF PENSYLVANIA.

State and County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
PENNSYLVANIA							
Somerset	.. ..	1. Hoyman's new 8 ft. bed	W. R. Johnson	1.343	69.90	22 00	8.10
,,	.. ..	2. Uhl's up. vein	,,	1.319	75.75	20.20	4.05
,,	.. ..	3. Korn's.....	,,	1.386	68.46	20.10	11.44
,,	.. ..	4. Schaeffer's....	,,	1.370	70.70	18.80	10.50
,,	.. ..	5. Hoyman's 8 feet as above	,,	1.363	71.50	18.30	10.20
,,	.. ..	6. Hoyman's 6 ft.	,,	1.362	68.54	19.80	11.66
,,	.. ..	7. Uhl's 7 ft. vein	,,	1.388	68.44	19.50	12.06
,,	.. ..	8. Weller's 4 feet	,,	1.321	69.10	19.99	11.00
,,	.. ..	9. Church land vein	,,	1.480	68.56	18.70	12.74
,,	.. ..	10. Hardin's vein	,,	1.491	66.36	17.60	16.04
		Mean results of the ten veins .	.. ..	1.382	69.73	19.59	10.68
MARYLAND.							
Alleghany	Maryland company.	Hoffman's mine, on main seam.	Silliman and Shepard....	1.380	82.01	15.00	2.99
,,	Cumberland coal..... .	,,	W. Hayes (Boston)....	..	77.86	15.60	6.54
,,	Savage river ..	,,	Dr. Jones (Washington)	..	78.00	19.00	3.00
,,	,,	,,	D. Jackson (Boston) ..	1.321	77.09	16.05	7.06
,,	Maryland company ..	,,	Dr. T. P. Jones (Washington)	1.291	72.50	22.50	5.30
,,	,,	,,	,,	1.333	81.00	15.00	4.00
,,	,,	Frost's mine	Dr. Ducatel....	..	70.00	20.57	9.50
,,	Dan's mount ..	Av. of 40 spec. ..	Johnson	1.311	73.59	16.04	10.37
,,	Cumbrlnd. coal	.. ..	Prof. Daniel ..	..	66.30	19.40	14.30
,,	,,	Maryland compy.	Johnson	1.431	67.26	14.42	18.32
,,	,,	Frostburg Neff's	,, ...	1.382	74.53	15.13	10.34
,,	,,	Howell's estate ..	Silliman	..	76.77	14.66	8.57
,,	,,	,,	Prof. Renwick .	..	81.00	13.00	6.00
,,	,,	Easby's	Johnson	1.305	77.25	16.23	6.52
,,	George's creek	Main vein, Lonaconing.....	Dr. Ducatel....	1.386	79.25	—	—
,,	,,	Third coal	,,	1 552	80.08	—	—
,,	,,	Fourth coal.....	,,	1.584	85.00	—	—
,,	Lonaconing company.	George's creek, thick bed	Johnson	1.346	70.75	16.03	13.22
,,	Maryland company.	Eckert mine on main seam ..	,, ...	1.437	68.56	15.62	15.82
,,	Frostburg	.. ..	Chilton.....	..	77.00	12.00	11.00
,,	,, ...	Mean of 2 anals.	Dr. J. Percy ..	..	78.80	9.47	11.73
,,	Big vein	,, 5 ,,	Dr. Higgins ..	1.320	88.05	8.54	3.41
,,	6 feet vein	,, 5 ,,	,, ..	1.340	86 01	8.68	5.31
,,	44 inch vein ..	,, 5 ,,	,, ..	1.391	74.24	7.13	18.63
,,	Oakland	,, 5 ,,	,, ..	1.290	73.34	12.54	5.12

FAT, BITUMINOUS COALS IN THE STATE OF OHIO.

County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
Portland	Talmadge	Upson's mine ..	W. W. Mather	1.264	53.404	44.298	2.283
Jackson.....	Lick Township	.. ..	,,	1.283	49.882	47.327	2.291
,, ...	Madison ,,	.. ..	J. L. Cassels ..	1.560	39.950	44.860	14.620
,, ...	,,	Cannel coal.....	,,	1.410	..	—	—
	Carr's Run	.. ..	R. C. T.	1.270	..	—	—
	Pomeroy	.. ..	Dr. J. Percy ..	..	76.70	18.70	4.60

FAT, BITUMINOUS COALS IN PENNSYLVANIA.

County.	Locality.	Names of Coal Seams.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
Venango	Shippensville..	Sandy Ridge ..	H. D. Rogers' State Report	..	49.80	43.20	7.00
„	6 M. F. of Franklin ..	.. ..	„	..	29.54	52.78	17.68
Beaver	Greersburg.. .	.. ..	„	..	30.12	36.00	33.88
Crawford	Conneaut l'e ..	.. ..	„	..	59.45	38.75	1.80
Mercer	Greensville....	.. ..	„	..	57.80	40.50	1.70
	„	.. ..	R. C. Taylor ..	1.275	..	—	—
	Orangeville....	.. ..	State report ..	..	53.45	43.75	2.80

MODERATELY BITUMINOUS, DRY, AND CLOSE BURNING COALS IN PENNSYLVANIA.

County or District.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific gravity.	Analysis.		
					Carbon.	Volatile matter.	Ashes.
Tioga or Blossburg Coal-field.	Blossburg ..	Coal Run, upper vein.	Taylor and Clemson ..	1.371	75.40	16.40	8.20
	„ Bear creek	Clement's coal ..	„	1.398	73.74	15.00	11.26
	„	Bloss's coal	„	1.405	73.00	15.60	11.40
	„	„	State report ..	..	62.80	32.80	5.20
	„ Johnson's Run....	Splint coal ..	Taylor and Clemson ..	1.493	69.30	14.60	16.10
	„ Coal Run	Slaty variety called cannel	„	1.750	33.40	8.40	58.20
	„ „	Pitch coal	„	1.500	54.26	18.50	27.24
	Head of Tioga.	New Hope vein..	R. C. Taylor ..	1.429	—	—	—
	Arbon company	Coal run, mean of 4 specimens	Johnson	1.323	73.11	16.12	10.77
Ralston and Lycoming Creek District	Ralston.....	Big vein	State report....	..	74.50	20.50	5.00
	„	„	Johnson	1.387	71.54	14.50	13.96
	Queen's Run ..	Av. of 40 specim.	„	1.331	73.44	18.81	7.75
	„	.. ..	State report ..	..	73.68	21.50	4.60
Bradford or Towanda Coal-field.	Schrœder, branch of Towanda creek..	Lower bed in three parts	W.R.Johnson	1.515	62.60	15.00	22.40
				1.448	70.00	17.40	12.60
				1.465	63.90	19.10	17.00
	„	Miller's old coal drift	„	1.377	68.10	20.50	11.40
				1.378	65.50	19.20	15.30
				1.349	74.97	19.30	5.73
	„	Mason's coal, upper part .. lower part....	„..	1.388	—	—	—
				1.400	—	—	—
Centre county ..	Snow-shoe	.. ..	State report....	..	76.73	21.20	2.07
„	Farrandsville	Select portion of Diamond vein.	Bache and Rogers	1.339	..	..	5.50
„	Lick Run.....	.. ..	State report....	..	66.21	20.72	13.07
Clearfield county	Karthaus.....	.. ..	W. R. Johnson	1.263	68.15	26.80	5.05
				1.292	80.49	12.83	6.68
„	„	Salt Lick.....	„	1.275	76.64	22.27	5.09
„	„	Upper seam	State report ...	..	78.20	13.00	8.80
„	„	Lower seam	„	..	70.50	24.80	4.70
„	Curwensville ..	Reed's vein.....	„	..	67.70	27.00	5.30
„	Caledonia	.. ..	„	..	54.50	37.00	8.50
„	„	.. ..	„	..	54.60	38.20	2.70

MODERATELY BITUMINOUS, DRY, AND CLOSE BURNING COALS IN PENNSYLVANIA.—(Continued.)

	County or District.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific gravity.	Analysis. Carbon.	Volatile matter.	Ashes.
		Karthaus.....	Main or 6 ft. seam	W. R. Johnson	..	68.15	26.80	5.05
		Philipsburg....	Best coal.....	W.R.Johnson and R. C. T.	1.308	70.00	22.30	7.70
		,, ...	,, ...	State report....	..	64.40	29.50	6.10
		,, ...	,, ...	Dr. Goddard ..	1.360	70.00	20.00	10.00
	Moshannon district.	near ,, ..	Showalter's 3 ft. vein	R. C. Taylor ..	1.358	—	—	—
		,, ,, ...	Goss's 6 ft. vein .	,, ...	1.357	—	—	—
		,, ,, ...	Coal hill	,, ...	1.500	—	—	—
		16 miles	Steed's mine	State report...	..	68.40	20.40	11.20
		17½ ,, ...	Leech's mine....	,, ...	..	67.93	20.32	11.75
	Cambria	Blair's Gap....	Portage Rail R...	T. G. Clemson.	..	77.00	15.00	8.00
	,, ...	,, ...	Mineral charcoal	,,	..	66.40	6.60	27.00
	,, ...	,, ...	Large bed	State report....	..	65.00	31.00	4.00
	,, ...	Summit	Portage Rail R...	Johnson	1.406	69.59	21.36	9.05
	Daughin	Short Mn.	South drift.....	Dr. Ellet, R.C.T.	1.330	75.50	15.30	9.20
				J. C. Booth....	..	..	16.90	—
	,,	,, ...	Big Flat's vein	M. C. Lea	..	71.20	17.32	13.46
				R. C. Taylor ..	1.395	—	—	—
				Rogers' reports	..	76.94	15.06	8.00
				J. C. Booth....	..	..	15.80	—
				M. C. Lea	1.391	78.80	13.20	8.00
	,,	Rattling Run Gap.	Perseverance vein	,, ...	..	76.10	16.90	7.00
				Rogers' reports	..	74.55	13.75	11.70
				Johnson	1.531	72.22	14.29	11.49
				mean of 6 exp's	..	—	—	—
	Lebanon ..	Yellow Springs	Back bone vein..	H. C. Lea	1.389	74.70	14.80	10.50
				J. C. Booth....	..	..	8.10	—
				M. C. Lea	1.391	80.33	8.86	10.80
	,,	,,	Kugler vein ..	,, ...	..	81.20	9.80	9.30
				,, ...	1.395	77.50	11.00	11.50
				Rogers' reports	1.410	79.55	10.95	9.50
	,,	Cold Spring ..	Six feet vein	H. Lea	1.403	76.30	11.10	12.60
	Bedford ..	Broad Top M...	Riddle's bank ..	Clemson	1.700	70.10	16.70	13.20
	,,	,,	Hopewell.....	Rogers' reports	..	84.80	11.20	4.00
	,,	,,	.. ..	W. R. Johnson	..	77.60	16.00	6.40
	Dauphin	Lyken's Valley	Bear Gap mines	R. C. Taylor ..	1.318	—	—	—
	,,	,,	1st sample.....	W. R. Johnson	1.391	87.95	7.60	4.45
	,,	,,	2nd ,, ...	,,	1.404	89.30	5.95	4.75
	,,	,,	3rd ,, ...	,,	1.416	85.70	10.00	4.30
	,,	,,	4th ,, ...	,,	1.374	88.70	4.60	6.70
	,,	,,	5th ,, ...	,,	1.376	87.75	8.35	3.90
	,,	,,	6th ,, ...	,,	1.395	88.65	8.30	3.05
	,,	,,	7th ,, ...	,,	1.382	87.20	7.84	4.15
	,,	,,	8th ,, ...	,,	1.398	83.99	11.85	4.16
	,,	,,	9th ,, ...	,,	1.378	87.00	7.30	5.70
	,,	,,	mean of 9 samples	,,	1.390	87.36	8.06	4.57
	,,	,,	Third Beb	H. D. Rogers' Report	..	88.25	8.85	2.90
	Schuylkill	Lower Mohantongo.	Klinger's or Rausch Gap.	J. R. Chilton, M.D.	..	89.71	4.48	5.81

Soft, free burning Red Ash, Anthracite in Pennsylvania. Coal seams of the South Mn.
Semi-bituminous Coals in Pennsylvania.

ANTHRACITE OF PENNSYLVANIA.

Description and Localities of Anthracite Coal Beds.		By whom examined or analysed.	Specific gravity.	Analysis of 100 parts of Anthracite.		
				Carbon.	Water, hydrr., and volatile matter.	Ashes, silica, earthy matter, iron, &c.
	Hard, White Ash Coal.					
Schuylkill Eastern Region.	Mauch Chunk	Olmsted	1.550	90.10	6.60	3.30
	"	Vanuxem	1.494	—	—	—
	" Summit Mines	W. R. Johnson	..	92.30	6.42	1.28
	" "	Karsten	..	86.00	8.00	6.00
	" "	M. C. Lea	..	87.00	7.30	5.70
	" 14 feet vein	Rogers's reports.	..	88.50	7.50	4.00
	" Hardest variety	"	..	87.70	6.60	5.70
	" mean of 2 results	Dr. J. Percy	..	92.60	5.15	2.25
	Nesquehoning	Taylor	1.558	—	—	—
	" 10 feet vein	Rogers's reports	..	86.60	6.40	7.00
	Tamaqua vein, D. east	M. C. Lea	..	91.00	5.50	3.50
	" D. "	Rogers's reports	1.570	92.07	5.03	2.90
	" E. "	"	1.600	89.20	4.54	6.26
	" R. "	"	1.550	87.45	7.55	5.10
	Tuscarora	"	..	88.20	7.50	4 30
	Forest Improvement, av. of 4 spec.	Johnson	1.477	92.12	4.83	3.05
Middle Coal-field.	Hazleton	Taylor	1.550	—	—	—
	Sugar Loaf mountain	W. R. Johnson, 3 samples	1.591 1.574 1.550	88.18 85.91 90.70	6.99 5.36 7.06	4.83 8.73 2.24
	Beaver Meadow	Taylor	1.600	—	—	—
	"	W. R. Johnson	1.630	85.34	9.60	5.06
	"	"	1.560	91.64	6.89	1.47
	"	"	..	92.30	6.42	1.28
	Girardville	Taylor	1.600	—	—	—
	Broad Mountain, W. W. Branch	"	1.700	—	—	—
Pine Grove District.	Big vein, Lorberry creek	"	1.472	—	—	—
	" "	M. C. Lea	..	85.90	7.20	6.90
	Locust Mount Coal and Iron Com.	Blake (Boston)	..	96.77	..	3.33
Red Ash coal	Sharp Mountain	Rogers's reports	1.540	80.57	7.15	3.28
Red Ash.—Free burning coal, with slight flame.	Black Spring Gap, 4 feet vein	Taylor	1.528	—	—	—
	" "	Rogers's reports	1.440	82.47	9.53	8.00
	" Peacock vein	Taylor & M.C.Lea	..	88.60	7.10	4.30
	" Grey vein	M.C.Lea & Taylor	1.379 1.395	86.00	4.50	9.50
	" The black compact pt	Rogers's reports	1.440	81.02	9.78	9.20
	" The Grey central part	"	1.330	81.40	11.40	7.20
	" Fishback vein	M. C. Lea	..	84.00	6.50	9.50
	" Lea vein	Rogers's reports	1.350	85.84	8.96	5 20
Stony Creek Estate, Lebanon Co. First Coal-field	Gold Mine Gap, Peacock vein	M. C. Lea	..	83.0	9.0	8.0
	" "	Rogers's reports	1.410	83.15	10.95	6.90
	" Heister vein	"	1.410	81.47	10.43	8.10
	Rausch Gap	M. C. Lea	..	78.90	11.00	10.10
	" Pitch vein	R. C. Taylor	1.387	—	—	—
	" Heister vein	"	1.454	—	—	—
		M. C. Lea	..	77.10	10.90	12.00
		Rogers's reports	1.450	77.23	10.57	12.30
White Ash Coal.	Broad Mountain	Dr. C. T. Jackson	1.593	..	..	7.80
	Lehigh or Summit Company, 1st	W. R. Johnson	1.613	87.48	7.51	5.01
	" 2d.	"	1.594	91.69	4.31	4.00
	" 5th	"	1.612	86.06	9.23	3.71
South and Middle Coal-field.	Mauch Chunk	Dr. J. Percy	..	84.98	4.82	10.20
	Buck Mountain	W. R. Johnson	1.559	91.02	5.90	3.08
	Shamokin (Snyder's)	Rogers's reports	..	89.80	6.10	4.00
	West Mahanoy	Taylor	1.371	—	—	—
North or Wyoming Coal-field.	Wilkesbarre, Blacksmith's coal	"	1.472	—	—	—
	" Warden's vein	Rogers's reports	1.403	88.90	7.68	3.49
	Wyoming	J. F. Frazer	..	91.20	4.50	4.30
	Lackawanna	Dr. C. T. Jackson	1.609	79.20	9.20	11.60
	" mean result	Johnson	1.421	88.98	6.36	4.66
	Scranton anthracite	Prof. H. D. Rogers	..	87.88	—	—
	Carbondale	Rogers's reports	1.404	90.23	7.07	2.70
Red Ash Coal. — Pottsville District. First or South Coal-field.	Peach Mountain, Delaware Co.	Taylor	1.446	—	—	—
	" mean of 40 speci.	Johnson	1.464	86.09	6.96	6.95
	" N. American Co.	Dr. C. T. Jackson	1.569	..	..	7.20
	Peach Orchard	"	1.532	..	..	6.60
	Salem vein	Taylor	1.574	—	—	—
	Plumbago vein, Sharp Mount	"	1.412	—	—	—
	Black Mine vein	H. Lea	..	88.40	6.80	4.80
	Gate vein	Dr. C. T. Jackson	1.609	..	..	6.60
	Shenoweth vein	Rogers's reports	1.500	94.10	1.40	4.50
	Neeley's Tunnel, 3d vein	"	1.550	89.20	5.40	5.40

ANTHRACITES OF THE UNITED STATES.

Description of Coal Beds.		Details.		Analysis of 100 parts of anthracite.		
State.	Locality of Mines.	By whom examined or analysed.	Specific gravity.	Carbon.	Water, hydr. and volatile matter.	Ashes, silica, earthy matter, iron, &c.
Rhode Island ..	Portsmouth mines	Dr. C. T. Jackson	1.850	85.84	10.50	3.66
	" "	"	..	87.50	7.00	5.50
	" "	"	..	77.50	13.00	9.50
	" "	"	1.770	84.50	10.00	5.50
	" "	L. Vanuxem	..	90.03	4.90	5.07
	" "	"	..	77.70	6.70	15.60
	Cumberland "	Dr. C. T. Jackson	..	77.00	7.60	15.40
	" "	"	..	39.70	7.80	52.10
	Providence "	"	..	72.00	..	28.00
	Portsmouth old mine.....	"	..	74.00	10.00	16.00
	Case's mine	"	..	97.00	..	3.00
Massachusetts.	Mansfield mine.....	"	1.690	87.40	6.20	6.40
	" "	"	1.780	92.00	6.00	2.00
	" "	"	1.710	92.00	6.00	2.00
	Worcester plumbaginous anthrac.	Dr. J. Percy	..	28.35	3.08	68.57
North Carolina	Near Leakesville, middle secondary rocks	W. B. Rogers ..	..	83.12	7.76	9.12
*England	Borrowdale } Plumbago..... {	L. Vanuxem	..	83.37	1 23	10.40
*Pennsylvania..	Bustletown }	"	..	94.40	.60	5.00
*England	Cornwall .. }	Saussure	..	95.00		4.00

BITUMINOUS COALS.

State and County.	Locality.	Designation of Coal Beds.	By whom analysed.	Spec. gravity.	Analysis. Carbon.	Volatile matter.	Ashes.
INDIANA.							
Parke county ..	Sugar creek	Foundry	D. D. Owen....	1.219	75.00	21.00	4.00
Vermilion.....	Brouillet's creek	.. ..	"	1.270	52.00	39.00	9.00
Vigo	Honey creek	.. ..	"	1.240	70.00	27.50	2.50
Sullivan.....	Busseron.....	Lick Fork	"	1.240	70.00	28.00	2.00
Fountain	Wabash	Coal creek mouth	"	1.260	60.00	25.00	25.00
Spencer.....	Anderson creek..	.. ..	"	1.270	45.00	—	—
	White river.....	.. ..	"	1.270	56.40	—	—
	Terre Haute	.. ..	"	1.240	50.80	—	—
	Cannelton	Cannel coal.....	W. R. Johnson	1.272	59.47	36.59	3.94
ILLINOIS	Rock river	Coal	Dr. D. D. Owen	1.340	45.50	44.50	10.00
	Vermilion	Danville	A. Morfit.....	..	48.50	47.20	4.30
	Western port....	.. ..	Johnson	1.290	..	32.80	—
	Ottowa.....	.. ..	J. F. Frazer ..	..	62.60	35.50	1.90
	Rockwell	.. ..	C. U. Shepard..	1.273	46.50	47.50	6.00
IOWA	Duck creek.....	W. bank of the Mississippi river	Dr. D. D. Owen	1.270	48.50	44.00	7.50
MISSOURI .. {	Cote-sans dessein, Callaway co. ..	Mastodon vein, forty-six feet thick ..... {	Booth and Boye J. R. Chilton, M.D.	.. 1.252	46.83 50.81	40.05 34.06	13.12 15.13
		Mammoth vein, twenty-four feet	"	1.250	50.78	34.20	15.02
	Osage river.....	.. ..	W. R. Johnson	1.200	51.16	43.50	5.34
ARKANSAS	Johnson county..	Spalpre's bluff ..	J. F. Frazer....	1.396	62.60	28.90	8.50
MAINE	.. ..	Peat	Dr. Jackson ..	..	21.00	72.00	7.00
Miscellaneous Analysis,							
Isle of Cuba....	Near Havana....	Asphalt	T. G. Clemson	1.190	34.97	63.00	2.03
	Near Matanzas ..	Asphaltum	"	..	..	..	13.50
South America.	Peru	Coxitambo	M. Boussingault	—	—	—	—
	Chili	Arauco	W. R. Johnson	1.324	67.62	30.00	2.38
	Brazil	.. ..	Karsten	1.289	57.90	40.50	2.60
	"	.. ..	"	1.483	38.10	33.50	28.40
Madeira Island	Brown coal.....	Or lignite.....	Johnstone	..	..	..	20.05
British America Bitumi[n] coal,							
Nova Scotia....	Pictou ..... {	Cunard's sample	Johnson	1.325	60.73	26.76	12.51
		Mining Associa'n	"	1.318	56.98	29.63	13.39
Cape Breton ..	Sydney.....	Mean of 2 species	"	1.338	67.57	26.93	5.50

* Mr. Vanuxem adds, by way of comparison, the analysis of 3 varieties of plumbago or graphite.

ANALYSIS OF COAL FROM ZWICKAU (SAXONY), BY BRÜCKNER.

Locality.	100 parts of dry combustible at 212° F. yield: Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Raw combustibles contain water per cent.
Russkohle Bürgerschact	82.10	5.34	0.65	0.37	10.45	1.09	8.00
Pechkohle ditto	80.00	5.50	0.88	0.40	11.54	1.68	8.00
Ditto Auroraschact	73.85	4.70	0.60	0.48	14.10	6.97	6.00

ANALYSIS OF COAL FROM HUNGARY BY NENDTVICH.

Locality.	100 parts of dry combustible at 100° C. contain: Carbon.	Hydrogen.	Sulphur.	Oxygen and Nitrogen.	Ash.	Water in raw combustibles per cent.	Coke.	Specific Gravity.
Comitat Crassoe:—								
Fit, Heil Dreifalt	83.84	4.36	0.38	11.79	8.24	3.19	78.07	1.390
„ Anton and Joseph	81.57	4.41	0.87	14.01	2.26	3.21	69.98	1.319
„ Emilia	78.37	3.92	0.74	17.70	1.55	7.30	70.60	1.366
„ Von Resicza	88.72	4.66	0.86	6.61	0.89	1.20	78.85	1.295
Comitat Barany and Tokay:—								
Fünfk, Makay	89.99	4.23	1.89	5.78	18.23	1.22	89.40	1.414
„ Paulovics	88.85	4.23	0.99	6.92	2.85	1.14	83.14	1.300
Comitat Gran and Comorn:—								
Fünfk, Magyaros	69.21	4.50	3.07	26.28	8.34	13.63	56.84	1.420
„ Ujfalu	69.72	4.82	5.10	25.45	9.74	13.60	60.26	1.430

ANALYSIS OF WOOD, TURF, AND BROWN COAL FROM SAXONY, BY BAER.

Kind of Fuel.	100 parts of dry fuel contain; Carbon.	Hydrogen.	Sulphur.	Oxygen.	Ash.	Water per cent. lost at 110° C. by fuel in natural condition.
Birch wood	48.89	6.19	..	43.93	0.99	13.14
Red beech wood	46.10	5.79	..	46.87	1.24	14.4 to 13.6
„	48.29	6.00	..	45.14	0.57	13.7
White beech wood	48.08	6.12	..	44.93	0.87	12.8
Oak	48.94	5.94	..	43.09	2.03	8.0
„	48.63	5.94	..	44.75	0.68	13.7
Pine, young stems	50.62	6.27	..	42.58	0.53	12.1
„ old floated stems	49.87	6.09	..	43.14	0.63	11.9
Turf, from Buchfeldt and Neulangen, 1st kind	51.54	4.69	33.90		9.87	15.7
„ „ „ 2nd „	50.13	5.36	35.24		9.37	21.7
„ Flatow, 1st kind	50.36	4.20	34.27		11.17	18.4
„ Linum, 2d „	53.69	4.84	31.73		9.74	16.4
„ „ 3d „	55.01	4.63	31.44		8.92	18.9
Brown coal or lignite, from Schönfeld, near Aussig, Bohemia	61.20	5.17	21.28		12.35	21.2
„ from Fürstenwalde, Rauen, moulded	55.59	4.16	19.06		21.19	11.0

ANALYSIS OF COAL AND BROWN COAL FROM HUNGARY, BY NENDTVICH.

Locality.	100 parts of dry combustible: Contain: Carbon.	Hydrogen.	Sulphur.	Oxygen.	Leave: Ash.	Coke.	Water per cent. at 110° C. on raw fuel.	Specific gravity.
HUNGARY :—								
Coal, Baranyer Comitat, Rosman's pit	86.88	4.37		8.74	10.69	86.47	..	1.356
„ „ Andrassevich pit, Fünfkirchen	88.30	4.80		6.90	5.82	82.82	..	1.313
„ Barbara pit, Szabolcs	89.69	5.03		5.27	10.33	81.55	..	1.350
„ Francis pit „	83.76	4.97		11.26	10.415	77.81	..	1.378
„ Michael's pit, Vassas	88.76	5.04		6.20	9.91	76.82	..	1.291
„ University domain, Vassas	86.72	5.09		8.19	12.05	78.57	..	1.339
„ Purkari pit, Krassöer Comitat	85.29	5.05		9.65	1.605	73.11	..	1.317
„ Gerlistye pit „	85.48	4.92		9.59	2.395	70.96	..	1.282
„ Markus pit „	84.54	4.96		10.50	2.615	68.17	..	1.287
„ Simon & St. Antony pit, Krassöer Comitat	82.54	4.35		13.10	10.53	76.33	..	1.423
Brown Coal, Tokodt, Coolnok, Sáriság } Gran Comitat	67.49	4.70		27.80	10.99	68.70	..	1.494
	71.55	5.19		23.25	5.66	..	..	1.359
	67.85	4.93		27.22	9.41	61.23	..	1.403
„ Zsemle, Comorn Comitat	71.89	4.79		23.31	4.35	59.55	..	1.347
„ Rudolphi seam 1 } Near Oedénburg	70.84	4.71	0.91	24.44	2.39	50.89	18.68	1.285
„ „ „ 2	72.18	5.18	0.55	22.63	2.08	55.98	17.00	1.300
„ Joseph „ 3	72.49	5.17	1.30	22.33	2.255	53.00	17.82	1.289
„ „ „ 4	71.36	5.09	1.63	23.54	4.645	46.00	17.10	1.334

ANALYSIS OF GERMAN COALS.

Locality.	100 parts of coal contain: Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Specific gravity.	Water per cent. in raw fuel.	By whom analysed.
HESSE :—									
Coal from Meismer	82.00	4.20	5.90		3.90	4.00	1.307	—	
„ „	62.18	5.47	18.05		9.30	5.00	1.208	—	
„ „	58.90	5.36	21.63		6.64	7.50	1.079	—	
„ Hirschberg	72.90	5.70	18.40		0.70	2.30	1.289	—	Graeger.
„ „	62.9	5.7	17.0		7.8	6.6	1.050	—	
„ Faulbach	60.6	5.5	18.4		8.0	7.5	1.130	—	
„ Gluckauf, near Mulhouse	36.65	3.84	12.32		..	47.19	2.5	—	
„ „ „	36.56	5.00	11.25		..	47.19	..	—	
„ Gallery d'Oppel	62.00	4.40	10.06	..	..	6.25	..	6.75	
„ „	62.35	4.50	11.90	..	..	9.05	..	7.20	
„ „	61.85	4.40	11.85	..	..	15.30	..	7.60	
„ Gallery de Doehlner	61.10	9.10	4.50	..	..	8.55	..	6.75	
„ „	60.10	11.00	4.45	..	..	12.25	..	7.20	
„ „	54.20	9.10	4.45	..	..	24.95	..	7.60	
Anthracite, Schoenfeld	64.68	5.31	21.36	..	..	8.65	—	—	Koettig.
„ Grosspriessen	63.56	4.81	25.12	..	..	6.51	—	—	
Coal, Grosspriessen	74.57	5.33	12.65	..	..	7.45	—	—	
„ „	70.95	5.18	13.55	..	..	10.32	—	—	
„ „	66.86	4.81	11.74	..	..	16.59	—	—	
„ „	73.36	5.41	10.92	..	..	10.31	—	—	
„ „	68.39	5.06	12.55	.	..	14.00	—	—	
„ „	58.68	4.48	9.83	..	..	27.01	—	—	

ANALYSIS OF GERMAN COAL BY W. BAER.

Locality.	100 parts of dry combustibles at 212° F. yield: Carbon.	Hydrogen.	Nitrogen.	Oxygen and Nitrogen.	Ash.	Water in raw combustibles.
SILESIA:—						
Pit, Kön. Louise, Pochhammer Seam	77.25	4.98	—	13.86	3.91	3.32
„ „ „ Reden	82.72	5.05	—	10.67	1.56	3.00
„ Hoym	72.96	4.38	—	12.12	10.54	4.80
„ Graf Hochberg	70.87	5.63	—	14.35	9.15	3.64
„ Neue Heinrich	80.82	4.96	—	8.14	6.08	2.21
„ Fuchs	79.30	5.06	—	10.56	5.08	3.95
„ David	79.18	4.55	—	11.08	5.19	4.70
„ Segen Gottes	82.02	5.22	—	10.25	2.51	3.97
WESTPHALIA:—						
Zeche, Kunstwerk	89 58	4.30	—	4.04	2.08	1.29
„ Sabyer u Neuak	85.62	4.65	1.71	7.64	2.09	1.29
„ Hundsnacken	88.23	3.86	—	3.69	4.22	1.33
„ Victoria Matthias	86.43	5.32	—	5.67	2.58	1.66
SAXONY:—						
Zeche, Von Löbezün	81.88	3.68	—	3.65	10.79	0.71
„ „ Wettin	77.53	5.13	—	5.30	12.04	0.82
SAARBRÜCK:—						
Pit, Gerhardt, Benst Seam	72.38	4.46	—	15.05	8.11	5.77
„ „ Heinrich „	70.20	4.70	—	13.27	11.83	5.27
„ Duttweiler, Beyer „	81.29	5.30	—	8.54	4.87	2.24
„ „ Natzmer „	83.63	5.19	0.60	9.66	1.52	1.87
„ Heinitz, Blücher „	80 53	5.06	—	11.91	2.50	2.31
„ „ Aster „	78.97	5.10	—	13.22	2.71	2.45
DUREN:—						
Pit, Centrum, Gyr „	90.62	4.50	—	1.31	3.57	1.26
„ „ Fornegel „	84.06	4.27	—	2.22	9.45	1.21
„ „ Grosskohl „	83.69	4.07	1.25	8.25	3.99	0.97
„ James, „ „	89.48	4.29	—	3.98	2.25	1.07
„ Ath, Grosslangenberg „	90.41	4.03	—	4.11	1.45	1.50
„ Neulauerweg, Grossathwerk Seam	89.32	3.80	—	2.71	4.17	1.48
„ „ Furth „	88.59	4.10	—	4.39	2.92	1.31

ANALYSIS OF COAL FROM SARDINIA, BY ABBENE AND ROSSI.

Locality.	100 parts of dry combustible contain: Carbon.	Hydrogen.	Oxygen.	Ash.
Canton Goneza	59.98	4.75	29.42	5.85

ANALYSIS OF COAL FROM TUSCANY, BY LA CAVA AND BUNSEN.

Locality.	100 parts of dry coal — Contain: Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Leave: Ash.	Coke.	By whom analysed.
Monte Massi (Tuscany)	62.00	5.00	0.92	17.83	14.25	56.5 to 57.6	La Cava.
Monte Bomboli	76.49	4.86	0.93	13.01	4.71	60.7 to 61.3	La Cava.
Monte Massi	73.63	5.28	17.89		3.20	—	Bunsen.
„	74.00	4.2	17.0		4.1	—	Bunsen.

ANALYSIS OF COAL FROM SILESIA AND WESTPHALIA, BY W. BAER.

Locality.	Water per cent.	Percentage in dry fuel.			
		Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
SILESIA :—					
Leopold pit	3.55	76.21	5.03	13.50	5.26
Fausta pit, Clara seam	3.75	76.63	4.98	13.92	4.47
,, Fausta seam	3.84	77.25	4.58	13.35	4.82
König's pit, Gerhard seam	4.15	79.51	4.87	12.96	2.66
,, Heintzmann seam	4.37	73.48	4.95	18.64	2.93
Pit Morgenroth	8.35	74.57	4.82	16.14	4.47
,, Leo	4.06	78.22	4.89	12.95	3.94
,, Louise, upper seam	3.81	70.02	4.99	14.87	10.12
,, lower ,,	3.27	70.79	5.32	19.34	4.55
,, Eugenicns Glück	6.83	73.20	4.93	19.11	2.76
,, Glückhilf	2.39	80.82	5.10	9.51	4.57
,, Königin Louise, Heinitz seam	3.35	73.91	4.85	17.59	3.65
WESTPHALIA :—					
Zeche Laura	1.05	74.81	4.35	8.76	12.08
,, Glücksburg, Franz seam	1.28	72.66	4.05	9.24	14.05
,, ,, Flottwell seam	1.08	77.25	4.02	8.14	10.59
,, der Engelsberg	1.23	85.90	4.56	6.33	3.21
,, Schafberg, Alexander seam	1.27	82.02	4.16	4.53	9.29
Tiefban Frauziska	1.19	77.10	4.55	11.79	6.56
,, Louise	2.25	78.05	5.05	12.92	3.98
Zeche Prasident	1.31	79.72	4.62	12.40	3.26
,, Fredrich Wilhelm	2.03	82.23	5.00	7.71	5.07
Coke, Fausta seam	4.96	87.82	1.43	5.14	5.61
,, Gerhard seam	5.88	90.01	1.46	6.30	2.23
Peat charcoal	5.28	78.42	4.01	14.77	2.80

ANALYSIS OF COALS FROM THE MINES OF HERACLIA—TURKEY.

Locality or Name of Mine.	Gaseous constituents.	Ashes.	Fixed Carbon.	By whom analysed.
Armoredjik	31.00	5.00	64.00	Rivot.
Zougoulaak	34.00	5.00	61.00	,,
Aladja-Aghry	45.00	4.00	51.00	,,
Silivria	49.50	7.00	43.50	Richardson
Rodosto, East of	48.00	12.00	40.00	,,
,, West of	48.00	5.00	47.00	,,
Erekli— Sea of Marmora	52.00	7.50	40.50	,,
Amasrah	40.00	6.00	54.00	Rivot.
,,	37.60	10.40	52.00	,,
Djattae-Aghazy	27.60	11.40	61.00	,,
Near Heraclia	30.00	7.40	62.60	,,
,,	31.00	7.80	61.20	,,
Djaoucb-Aghazy	35.40	4.80	59.80	,,
Aladja-Aghazy	30.60	11.40	58.00	,,

COMPOSITION OF COAL FROM DISCO ISLAND, ARCTIC REGIONS, BY DR. FYFE.

Locality.	Specific gravity.	Coke.		Volatile matter.
		Carbon.	Ash.	
Disco Island	1.3848	39.56	9.84	50.60

ANALYSES OF COAL (BRITISH) BY BAER AND VAUX.

Locality.	100 parts of dry combustible							Water per cent. at 110° C. in raw fuel.	Specific gravity.	By whom analysed.
	Contain					Leave				
	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Coke.			
BRITISH :—										
Hawthorn, Hartley, Newcastle (caking).	76.87	4.99	..	11.99	..	6.15	..	1.2 to 0.85	..	Baer.
Humricks, Stockton	86.86	5.00	..	7.36	..	0.78	..	0.99	..	Baer.
Hawthorn, Hartley, Newcastle (caking).	93.04	0.26	..	1.61	..	5.09	..	..	..	Baer.
Newcastle caking	81.41	5.83	2.05	0.75	7.90	2.07	66.70	1.355	1.276	Vaux.
Wigan cannel.....	80.07	5.53	2.12	1.50	8.09	2.70	60.36	0.906	1.276	Vaux.
St. Helen's, Lancashire, Rushy park.	75.80	5.21	1.92	0.90	11.89	5.17	65.00	3.232	1.279	Vaux.
Staffordsh. Wolverhampton	78.57	5.29	1.84	0.39	12.88	10.30	57.21	11.29	1.2785	Vaux.
"	..	..	..	2.57	..	3.01	58.20	8.39	1.276	Vaux.
Anthracite, Wales."	90.39	3.28	0.83	0.91	2.97	1.61	92.10	2.00	1.3925	Vaux.
Lignite, Bovey, Heathfield, Chudley, near Exeter.	66.31	5.63	0.56	2.36	22.86	2.27	30.71	34.66	1.129	Vaux.
Turf	54.02	5.21	2.30	0.56	28.17	9.73	29.36	25.56	0.8495	Vaux.
OREGON TERRITORY.....	..	..	..	..	..	35.49	66.50	5.624	1.578	Vaux.

COMPOSITION OF COAL ASHES.

—	St. Etienne (Berthier)	Cantyre (Thomas)	—	Elswick (Richardson)
Silica.....	..	45.5	Silica and alumina	90.08
Alumina, insoluble in acids	62	43.9	Oxide of iron	3.63
Alumina, soluble in acids	5		Lime.....	1.49
Lime	6	3.2	Magnesia.....	trace.
Magnesia.....	8	3.3	Sulphate of lime	0.93
Oxide of magnesia	3	—	Potash	trace.
Oxide and sulphuret of iron	16	1.4	Moisture	3.80
Sulphuric acid	..	1.7		
Chlorine	..	.1		
Potash and soda.....	..	.3		
	100	99.4		99.93

COMPOSITION OF THE ASHES OF PEAT, BY BERTHIER.

—	Chateau Landon.	Voitsumra.	Troyes.	Vassay.	Framont
Gelatinous silica	15.0	Silica 36.5	—	—	40
Alumina	7.0	17.3	and oxide iron 14	—	30
Carbonate and caustic lime	63.0	—	—	Carbonate 51.5	—
Oxide of iron	7.0	33.0	—	11.5	—
Carbonate of potash	0.5	—	—	—	—
Clay, insoluble in acid.....	7.5	—	and silica 26	11.0	—
Zinc	—	2.0	23	—	30
Magnesia	—	3.5	14	—	—
Sulphate of lime.....	—	4.5	—	26.0	—
Muriate of lime	—	0.5	—	—	—
Carbon	—	2.7	Carbonic acid and sulphur 23	—	—
	100.0	100.0	100	100.0	100

COMPOSITION OF THE ASHES OF DIFFERENT VARIETIES OF COKE, BY GAULTIER.

Locality.	Sulphate of lime.	Silica.	Alumina.	Carbonate of lime.	Carbonate of magnesia.	Oxide of iron.	Oxide of manganese.
ENGLISH :—							
Iron bridge	12.55	42.10	34.40	4.80	0.40	5.28	trace.
Dudley	8.64	35.40	30.40	6.48	..	18.68	,,
Merthyr Tydvill	4.56	41.60	35.44	6.46	1.08	10.80	,,
ST. ÉTIENNE :—							
Puits St. Henri	2.40	73.20	14.40	0.80	0.70	7.98	,,
,, du fils	2.40	54.90	37.00	3.20	..	2.30	,,
,, de Carrode	4.90	56.50	23.00	0.40	0.76	14.38	,,
,, Robert menu	5.60	44.50	34.34	7.00	0.50	7.18	,,
,, dessus	2.20	50 00	32.00	1.40	0.70	13.28	,,
,, des planches	3.60	43.50	36.20	6.20	0.50	9.42	,,
,, de la grande fendue	3.50	58.20	34.00	0.30	0.30	3.32	,,
RIVE-DE-GIER :—							
Puits de la grande Croix	3.20	55.00	19.80	8.80	..	13.00	,,
,, des Combes	8.70	36.30	11.00	24.20	..	19.06	,,
,, de St. Mathieu	4.90	55.00	22.24	5.50	8.80	3.32	,,

ANALYSES OF BROWN COAL OR LIGNITE FROM PRUSSIAN SAXONY, BY F. BISCHOFF.

Locality.	Freshly mixed coal yielded: Water per cent.	Specific Gravity.	Percentage in dry fuel: Carbon.	Hydrogen.	Oxygen and Nitrogen	Ash.
Riestedt, George Pit	33.4	1.197	57.13	4.16	27.05	11.66
,, ,, fossil wood	31.7	1.218	61.13	5.09	31.95	1.83
Voigtstedt, earthy, with fossil wood	49.2	1.241	49.15	4.45	32.25	14.15
Löderburg earthy	49.5	1.219	45.30	4.90	31.95	7.85
Mertendorf ,,	48.6	1.233	49.45	5.17	24.84	21.54
Altenweddingen ,,	47.3	1.194	57.71	4.75	22.94	14.60
Biere	46.9	1.200	55.92	4.77	22.48	16.83
Tollwitz earthy	49.6	1.257	57.51	5.29	25.40	11.80
Pretzsch ,,	50.7	1.213	50.80	4.96	26.20	18.04
Teuditz ,,	48.6	1.263	54.62	5.28	27.90	12.80
Brumby ,,	40.6	1.263	47.78	4.28	18.42	29.52
Lebendorf ,,	42.7	1.318	47.73	4.34	17.64	30.29
Zscherben ,,	49.5	1.207	57.82	5.59	24.53	12.06
Runthal, Upper Seam ,,	50.0	1.139	59.35	5.86	26.31	8.48
,, Lower ,, ,,	48.7	1.127	65.94	6.07	25.67	2.32
Wörschen ,,	49.9	1.142	60.76	5.99	23.13	10.12
Gorstewitz ,,	—	—	67.11	10.28	10.02	12.59
Rauen (Förderkohle)	14.83	—	59.00	4.55	25.77	10.68

ANALYSES OF GERMAN BROWN COAL OR LIGNITE, BY W. BAER.

Locality.	100 parts of combustible dried at 212° F. yielded: Carbon.	Hydrogen.	Oxygen and Nitrogen	Ash.	Water per cent in raw combustibles.
Rauen, in pieces (1)	61.38	4.91	23.57	10.14	38.66
,, ,, (2)	60.00	4.56	25.43	10.01	25.82
Frankfurt-on-the-Oder	59.65	4.86	26.41	9.08	16.07
Tollwitz (1)	63.14	5.17	19.99	11.10	51.46
,, (2)	64.70	5.63	18.11	11.56	39.52
,, (3)	62.07	5.56	19.90	12.47	18.03
Zscherben	64.26	5.76	17.44	12.54	45.37
Biere	52.80	4.99	15.67	26.54	31.24
Stechall	64.53	5.17	25.35	4.95	43.67
Wittenberge	64.07	5.03	27.55	3.35	17.26

ANALYSES OF AUSTRIAN LIGNITE, BY SCHRÖTTER.

Locality.	100 parts of dry combustible contain: Carbon.	Hydrogen.	Sulphur.	Oxygen.	leave: Coke.	Ash.	Specific Gravity.
Wildshut	53.79	4.26	0.98	25.39	15.58	54.7	1.306
Thallern	49.58	3.84	4.56	22.68	19.34	63.7	1.413
Glognitz	57.71	4.49	3.12	22.14	12.54	54.4	1.364
Pitch coal from Grünbach	69.66	4.29	1.71	17.42	6.93	60.9	1.320

ANALYSES OF LIGNITE, CHIEFLY OF FRANCE, BY BERTHIER AND DUFRÉNOY.

Locality.	100 parts of combustible contain: Carbon.	Volatile matter.	Ash.	By whom analysed.
Lignite du Val Pineau	36.5	57.0	6.5	Berthier.
„ Gurdanne	41.8	43.0	15.2	
„ Fureau	36.0	53.0	11.0	
„ Saint Martin de Vaud	45.0	44.0	11.0	
„ Koep Fuarch	41.0	47.0	12.0	
„ Elbogen	24 0	69.3	6.7	
„ Alphie	27.5	56.5	16.0	
„ Triphilis	31.0	51.0	18.0	
„ Konnin	34.0	53.5	12.5	
„ Baffin's Bay	58.8	29.3 liquid, 16.7 gaseous	5.2	
Bituminous wood	44.1	37.1 liquid, 17.4 gaseous	1.4	
Ditto ditto	37.1	61.5	1.4	
Lignite Utweiller (Rhine)	67.3	31.8	0.9	
„ Germany	42.9	52.5	4.6	
„ Edon (Charente)	39.0	50.0	11.0	
„ St. Lon (Basses-Pyrénées)	48.4	46.0	5.6	
„ L'Enfant dort (Bouches-du-Rhone)	49.3	46.8	3.9	
„ Minerne (Aude)	32.6	57.4	10.0	
„ Dauphin (Basses Alpes)	43.6	49.0	7.4	
Jet St. Colombe	60.4	37.9	1.7	Dufrénoy.
Lignite Marseilles	49.3	46.8	3.9	
„ Dauphiné	43.6	49.0	7.4	
Fossil wood	44.1	37.1 liquid, 17.4 gaseous	1.4	
Bituminous wood	38.4	39.3 liquid, 19.8 gaseous	2.5	
Cologne earth	37.4	31.3 liquid, 25.6 gaseous	5.7	

ANALYSES OF TURF FROM KAISERSLAUTERN, NEAR HOMBERG, BY WALZ.

Locality.	100 parts of combustible dried at 212°F. yielded: Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Ash.	Water per cent in natural condition.
Mackobächer Moor	62.15	6.29	1.66	27.20	2.70	8.0
Steinwender	57.50	6.90	1.75	31.81	2.04	8.3
Neidermoor	47.90	5.80	—	42.80	3.50	8.0

ANALYSES OF TURF FROM GERMANY, BY JAECKEL.

Locality.	Undried turf gave:		100 parts of dry turf, ash deducted, yielded:		
	Ash.	Water.	Carbon.	Hydrogen.	Nitrogen and Oxygen.
Havel Flat, near Berlin (1)	8.13	17.63	56.43	5.32	38.25
Ditto ditto (2)	5.33	19.32	53.51	5.90	40.59
Ditto ditto (3)	5.51	18.89	53.31	5.31	41.38
Linnum Moor	8.36	31.34	59.43	5.26	35.31
Friesack Moor	8.91	21.82	—	—	—
Cassel	18.27	26.60	—	—	—
Near Hamburg	1.89	18.83	57.12	5.32	37.56

ANALYSES OF TURF (CHIEFLY FRENCH), BY BERTHIER, DIDAY, AND SAUVAGES.

Locality.	Carbon.	Volatile matters.		Ash.	Water.	By whom analysed.
		Liquid.	Gas.			
Demarary	23.5	36.7	22.5	17.3	—	Berthier.
Château-Laudon	26.0	31.0	28.0	15.0	—	
Clermont (Oise)	30.1	28.4	24.1	17.4	—	
Reims	34.7	39.9	18.6	6.8	—	
Voitsuma (Bavaria)	38.6	38.5	21.2	1.7	—	
Rue (Somme)	21.	72.0		7.0	—	
New Abbeville (Somme)	23.	72.2		4.8	—	
Velleron (Vaucleuse)	17.3	65.3		17.4	—	Diday.
Sécheval (Arrondissement Rocroy and Nêzières)	22.0	39.2		8.3	30.5	Sauvages.

ANALYSIS OF FUEL FROM RUSSIA, BY WOSKRESSENSKY.

Variety of Fuel.	Locality.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
Anthracite	Gruschewskaja Stanitza (Don Cossacks)	93.785	1.732	2.940	1.543
"	Lissitschja Balka	90.598	2.840	1.712	4.85
Coal	Solikamsk (Govt. Perm)	72.228	4.275	17.457	6.04
"	Bachmut	71.173	4.977	21.502	2.348
"	Charkow (near Petrowska Sloboda)	72.249	3.524	21.067	3.16
"	Tschernolesnaja (Caucasian)	70.724	4.855	21.705	2.716
"	Kaluga (near Selinina)	63.934	4.21	12.456	19.38
"	Wladimir (on the Oka)	60.262	4.43	28.848	6.46
"	Rjasan (on the Ranowa)	50.259	4.51	19.271	25.96
Brown coal	Tiflis	63.346	5.678	27.836	3.040
"	Irkutsk (on the Argunia)	47.462	4.56	33.028	14.95
Bit. shale	Kurland (on the Windau)	20.60	2.75	19.73	56.92
Turf	St. Petersburg	39.084	3.788	51.088	6.04

STATISTICS OF THE PRODUCTION OF METALS DURING 1854, BY WHITNEY.

Locality.	Gold. lbs. Troy.	Silver. lbs. Troy.	Mercury. lbs. Avoirdupois.	Tin. tons.	Copper. tons.	Zinc. tons.	Lead. tons.	Iron. tons.
Russia	60,000	58,000	..	..	6,500	4,000	800	200,000
Sweden	2	3,500	..	..	1,500	40	200	150,000
Norway	..	17,000	..	..	500	..	..	5,000
Great Britain	100	70,000	..	7,000	14,500	1,000	61,000	3,000,000
Belgium	..	..	..	..	..	16,000	1,000	300,000
Prussia	..	30,000	..	..	1,500	33,000	8,000	150,000
Hartz.	6	30,000	..	..	150	10	5,000	—
Saxony	..	60,000	..	100	50	..	2,000	7,000
Rest of Germany	..	3.000	..	..	..	..	1,000	100,000
Austria	5,700	90,000	500,000	50	3,300	1,500	7,000	225,000
Switzerland	..	..	..	..	..	..	..	15,000
France	..	5,000	..	..	..	..	1,500	600,000
Spain	42	125,000	2,500,000	10	500	..	30,000	40,000
Italy	..	..	..	..	250	..	500	—
Africa	4,000	..	..	..	600	..	—	—
East Indies and Southern Asia	25,000	..	..	5,000	3,000	..	—	—
Australia and Oceania	150,000	8,000	..	..	3,500	..	—	—
Chili	1,000	250,000	..	..	14,000	..	—	—
Bolivia	1,200	130,000	..	..	..	..	—	—
Peru	1,900	30,000	200,000	1,500	..	..	—	—
Ecuador, New Grenada, &c.	15,000	130,000	..	..	1,500	..	—	—
Brazil	6,000	700	..	..	..	..	—	—
Mexico	10,000	1,750,000	..	..	..	..	—	—
Cuba	..	..	..	..	2,000	..	—	—
United States	200,000	22,000	1,000,000	..	3,500	5,000	15,000	1,000,000
Total	481,950	2,695,200	4,200,000	13,660	56,900	60,550	133,000	5,817,000

STATISTICS OF THE PRODUCTION OF THE METALS IN RUSSIA DURING 1852.

The quantity of gold obtained from the Government mines was:—

	Puds.*	Lbs.	Sol.	Doli.
Ekaterinburg	34	38	38	60
Bogosslowsk	40	4	30	—
Goroblagodat	10	3	16	—
Slatoust	49	23	63	—
Nertschinsk	72	19	44	32
Altai	37	23	40	—
Total from Government mines	244	31	9	92
Private mines	1122	39	18	5
Total	1367	30	58	1

The quantity of silver containing gold amounted to 1073 puds, 32 lbs. 85 sol. 25 doli, all, with the exception of 17 sols., from Government works.

Of platinum the Government mines yielded only 3 lbs. 30 sol.

The private mines gave 16 puds, 19 lbs., 30 sol.

The amount of gold obtained from 1823 up to 1848 was as follows:—

	Puds.	Lbs.	Sol.	Dol.		Puds.	Lbs.	Sol.	Dol.		Puds.	Lbs.	Sol.	Dol.
1823	105	6	48	24	1832	384	24	4	45	1841	655	12	28	18
1824	204	20	74	—	1833	378	22	69	72	1842	908	13	18	72
1825	232	18	2	—	1834	375	..	18	84	1843	1241	26	54	26
1826	231	6	18	—	1835	385	26	5	24	1844	1276	24	33	83
1827	281	30	74	—	1836	398	..	93	90	1845	1304	14	58	90
1828	290	32	11	60	1837	442	20	43	21	1846	1628	28	12	74
1829	288	8	77	72	1838	493	13	35	24	1847	1741	7	91	76
1830	352	32	54	72	1839	492	39	43	42	1848	1726	35	24	48
1831	364	27	60	87	1840	533	39	87	84					

Of the other metals there were produced:—

	Puds.	Lbs.
Copper	410,572	19
Lead	40,315	23
Cast-iron	13,159,759	37
Steel	78,876	18
Wrought-iron	10,292,692	36
Other metallic products	2,400,847	23

* 1 pud = 40 Russian pounds; 1 lb. = 96 solotnik; 1 solotnik = 96 doli.

No. I.—CLASSIFICATION OF ACCIDENTS IN BRITISH COAL MINES, BY HERBERT MACKWORTH, ESQ.

Year.	District.	Explosions of Fire-damp.	Falls of Coal.	Falls of Stone.	Total Falls in Mine.	Over-winding.	Ropes and Chains Breaking.	Whilst Ascending or Descending.	Falls into Shaft from Surface.	Things falling from Surface.	Falling from part way down.	Things falling from part way down.	Miscellaneous in Shafts.	Total in Shafts.	Explosions of Gunpowder.	Suffocation by Gases.	Irruptions of Water.	Falling into Water.	On Inclines Underground.	By Trams Underground.	By Machinery Underground.	Sundries Underground.	Total Miscellaneous Underground.	By Machinery on Surface.	Boilers Bursting.	Miscellaneous on Surface.	Total on Surface.	Gross Totals of Accidents.
1851	Scotland	2	12	33	45	2	2	4	4	2	3	4	7	28	0	2	0	0	1	0	0	2	5	2	0	2	4	84
1852		5	9	14	23	0	2	2	3	3	3	3	3	19	0	0	2	0	1	1	1	4	9	1	0	0	1	57
1853		10	6	25	31	3	1	5	3	0	5	3	1	21	1	2	0	0	2	2	0	0	7	0	0	0.	0	69
1851	Northumberland, Durham, Cumberland	10	10	21	31	0	1	0	5	1	3	3	2	15	1	0	1	0	3	16	1	5	27	2	0	10	12	95
1852		10	13	31	44	0	3	6	3	0	4	0	7	23	1	1	0	0	2	19	1	0	24	5	2	8	15	116
1853		8	16	39	55	0	1	8	4	1	4	2	7	27	2	1	0	1	2	16	2	5	29	2	5	7	14	133
1851	Yorkshire, Derbyshire, Nottinghamshire, Warwickshire.	17	11	18	29	0	1	0	7	3	7	0	3	21	0	0	0	0	0	2	0	1	3	3	0	2	5	75
1852		11	12	21	33	1	5	3	8	0	5	2	2	26	3	1	1	0	3	6	0	2	16	2	0	2	4	90
1851	Lancashire, Cheshire, North Wales	35	13	32	45	1	1	12	5	3	7	7	1	37	1	3	0	1	3	3	3	1	15	1	1	3	5	137
1852		31	13	42	55	1	2	14	10	4	3	6	2	42	1	3	3	9	1	2	0	3	13	1	0	4	5	146
1853		21	14	53	67	1	4	12	2	3	2	10	2	36	3	2	0	1	2	8	1	3	20	4	0	3	7	151
1851	Staffordshire, Shropshire, Worcestershire	20	71	36	107	3	7	11	23	2	3	4	11	64	2	0	0	0	0	1	0	8	11	2	2	2	6	208
1852		20	91	31	122	2	3	9	22	3	4	1	1	45	1	1	0	0	0	1	0	2	5	3	0	5	8	200
1853		22	82	24	106	6	2	7	20	5	5	7	8	60	4	2	0	0	1	0	0	1	8	1	0	1	2	198
1851	South Wales, Monmouth, Gloucester, Somerset	14	22	28	50	2	5	4	1	1	2	5	2	22	1	1	0	0	0	1	0	4	7	1	4	1	6	99
1852		14	18	38	56	1	2	6	6	0	1	3	1	20	5	1	3	0	2	0	0	1	12	2	3	5	10	112
1853		18	20	43	63	1	5	5	10	1	5	2	5	34	3	1	0	0	3	7	1	0	15	2	0	3	10	140
1854		13	20	48	68	0	3	6	6	3	6	3	7	34	1	1	2	0	5	8	0	0	17	2	0	5	7	139

No. II.—ACCIDENTS IN BRITISH COAL MINES, BY HERBERT MACKWORTH, ESQ.

Year.	District.	Number of Fatal Accidents.								Number of Deaths ensuing.						
		Explosions of Fire-damp.	Falls of Roof and Coal.	In Shafts.	Miscellaneous, Underground.	On Surface.	Total.	Number of Colliers employed, by census.	Fatal Accidents per 1000 persons employed.	Deaths per 1000 persons employed.	Explosions of Fire-damp.	Falls of Roof and Coal.	In Shafts.	Miscellaneous, Underground.	On Surface.	Total.
1851	Scotland	2	45	28	5	4	84	32,961	2.5	4.5	62	52	28	4	4	150
	Northumberland, Durham, Cumberland	10	31	15	27	12	95	42,437	2.2	3.3	57	32	15	27	12	143
	Yorkshire, Derbyshire, Nottinghamshire, Warwickshire, and Leicestershire	17	29	21	3	5	75	33,195	2 2	4.1	76	30	21	3	5	135
	Lancashire, Cheshire, and North Wales	35	45	37	15	5	137	36,243	3.7	5.0	70	48	39	18	6	181
	Staffordshire, Shropshire, Worcestershire	20	107	64	11	6	208	32,449	6.4	7.5	41	111	75	12	6	245
	South Wales, Monmouth, Gloucester, and Somerset	14	50	22	7	6	99	38,932	2.5	3.3	15	54	41	9	11	130
	Total	98	307	187	68	38	698	216,217	3.23	4.5	321	327	219	73	44	984
1852	Scotland	5	23	19	9	1	57	....	..	..	5	23	24	8	1	61
	Northumberland, Durham, Cumberland	10	44	23	24	15	116	....	..	..	38	44	28	24	19	153
	Yorkshire, Derbyshire, Nottinghamshire, Warwickshire, and Leicestershire	11	33	26	16	4	90	....	..	..	22	35	21	19	4	108
	Lancashire, Cheshire, and North Wales	31	55	42	13	5	146	....	..	..	91	56	57	20	5	229
	Staffordshire, Shropshire, and Worcestershire	20	122	45	5	8	200	....	..	..	25	134	46	6	8	219
	South Wales, Monmouth, Gloucester, and Somerset	14	56	20	12	10	112	....	..	..	83	57	26	39	11	216
	Total	91	333	175	79	43	721	....	..	..	264	349	209	116	48	986
1853	Scotland	10	31	21	7	0	69	....	..	..	15	31	27	8	0	81
	Northumberland, Durham, Cumberland	8	55	27	29	14	133	....	..	..	19	58	29	30	14	150
	Yorkshire, Derbyshire, Nottinghamshire, Warwickshire, and Leicestershire	11*	33	26	16	4	90	....	..	..	22	35	28	19	4	108
	Lancashire, Cheshire, and North Wales	21	67	36	20	7	151	....	..	..	99	71	40	20	7	237
	Staffordshire, Shropshire, and Worcestershire	22	106	60	8	2	198	....	..	..	35	115	65	13	3	331
	South Wales, Monmouth, Gloucester, and Somerset	18	63	34	15	10	140	....	..	..	36	63	39	15	10	163
	Total	90	355	204	95	37	781	....	..	..	226	373	228	105	38	970

* The numbers of 1853 repeated.

No. III.—DEATHS IN PRUSSIAN MINES.

Year.	District.	Amount raised.	Workmen employed.	By Falls of Minerals.		In Shafts.		By Gases.		By Machinery.		Miscellaneous Accidents.		Totals.	
				Total.	Per 1000 persons.	Total.	Per 1000 persons.	Total.	Per 1000 persons.	Total.	Per 1000 persons.	Total.	Per 1000 persons.	Total.	Per 1000 persons.
		Tons.													
1853	Coal Mines	7,860,557	41,398	36	0.869	18	0.435	18	0.435	15	0.362	2	0.048	89	1.149
	Lignite Mines	3,342,988	7,929	6	0.757	3	0.378	..	..	1	0.126	..	..	10	1.261
	Metalliferous Mines	£648,753	24,509	13	0.530	5	0.204	6	0.245	1	0.041	2	0.082	27	1.102
	Other Mines		2,683	8	2.982	..	..	..	..	..	..	..	..	8	2.982
	Total	....	76,519	63	0.823	26	0.340	24	0.314	17	0.222	4	0.052	134	1.751
1852	Coal Mines	....	36,039	29	0.805	12	0.333	8	0.222	7	0.191	3	0.083	59	1.637
	Lignite Mines	....	7,599	16	2.105	2	0.263	1	0.132	..	..	..	..	19	2.500
	Metalliferous Mines	....	18,366	8	0.461	4	0.230	1	0.057	1	0.057	4	0.230	18	1.035
	Other Mines	....	2,384	8	3.342	..	..	..	..	..	..	..	..	8	3.342
	Total	....	63,388	61	0.962	18	0.284	10	0.158	8	0.126	7	0.110	104	1.640

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